# Overview of Evolving ENERGY STAR Qualified Homes Program & Methodology for Estimating Savings

In 1995, EPA launched its ENERGY STAR Qualified Homes program, an initiative to transform the housing market through the voluntary adoption of efficient technologies and practices. ENERGY STAR qualification signifies high-quality, meaningfully efficient, and cost-effective new homes that provide a competitive advantage to Partners relative to unqualified homes.

From time-to-time throughout the 1995-2009 tenure of the program it has become necessary to modify the ENERGY STAR platform, more robustly establish its technical underpinnings, and adjust its market strategy to keep pace with changes, upgrades, improvements and/or increases in:

- National and state residential energy codes, energy conservation legislation and environmental regulations
- Utility rates and mortgage terms & interest rates
- Housing sector demographics and market conditions
- Prevalent home construction design and building practices
- Price, availability, and performance specifications of code and energy-efficient HVAC equipment, building materials, windows, lighting, appliances, and products
- RESNET-approved HERS algorithms and HERS Reference Home specifications; HERS rater/provider infrastructure viability; and residential energy computer simulation software

Since the inception of the program, one key programmatic task has been the estimation of average savings per home for each iteration of the guidelines, which is used to estimate overall program impacts and assess meaningful savings.

In brief, projections of national energy, utility bill, and greenhouse gas emission savings attributable to EPA's ENERGY STAR Qualified Homes program are estimated in the following manner. A broadly representative group of ENERGY STAR qualified homes is selected for analysis and their energy budgets simulated using the most commonly used RESNET-accredited HERS[1] rating software program for ENERGY STAR qualification. This software also automatically calculates the energy budgets of corresponding HERS reference homes, which form the baseline from which savings are measured on the HERS scale. Because the HERS reference homes have traditionally been roughly aligned with the predominant energy codes in use, EPA has also used these homes as a basis from which to measure program savings. The differences in energy consumption between the ENERGY STAR qualified homes and these HERS reference homes are calculated and constitute the basis of the savings estimates.

This paper provides an overview of the evolving guidelines and discusses the methodology used to estimate average savings per home for each of the program iterations.

## 1995-2005: ENERGY STAR Qualified Homes Guidelines "Version 1"

The initial implementation of the ENERGY STAR Qualified Homes guidelines introduced the concept of a voluntary market-transformation program for new homes by promoting a focused set of key energy efficiency measures coupled with third-party verification. Key measures included reduced infiltration, duct sealing, low-e windows, and efficient HVAC systems.

The assumptions and methodology used to determine the energy, utility bill, and greenhouse gas emissions savings of the first generation of ENERGY STAR qualified homes has been described in previous papers (see references 1 & 2). At the beginning of the program in 1995, a GIS-based analysis completed by Lawrence Berkeley National Lab and EPA estimated the national average energy savings of a "Version 1" ENERGY STAR qualified home, as shown in Exhibit 1.

[1] The Home Energy Rating System (HERS) is a standardized methodology for evaluating the relative energy efficiency of homes, which is maintained by the Residential Energy Services Network (RESNET). For more information on RESNET, see http://www.natresnet.org/. For a copy of the current RESNET standards, see http://www.resnet.us/standards/mortgage/default.htm

**Exhibit 1: ENERGY STAR Qualified Home "Version 1" Annual Savings**

| Metric | Savings Assessment |
|---|---|
| Electricity | 1,878 kWh |
| Natural Gas | 142 therms |
| Utility Bill | $235 |
| Greenhouse Gas Emissions | 0.586 MTCe |
| **Analytic Parameter** | **Value** |
| Code Baseline | 1993 MEC |

## 2006-2011: ENERGY STAR Qualified Homes Guidelines "Version 2"

Between 1995 and 2005 several developments had an accumulating bearing on the estimated savings for Version 1 of the guidelines. Most significant were HERS scoring algorithm modifications that attempted to address fuel-neutrality concerns. By 2005 the accumulation of the changes had become considerable. Then two additional major developments necessitated action:

- The pending shift from 1993 MEC to the International Code Council's 2003 International Energy Conservation Code with 2004 Supplement (herein referred to as the 2004 IECC) as the basis for the HERS Reference Home, along with more stringent minimum HVAC equipment efficiency dictated by the National Appliance Energy Conservation Act (NAECA)
- The inclusion of lighting and appliance end-uses for the first time in the HERS scale

To keep pace with all these developments, a full-fledged re-specification of the ENERGY STAR Qualified Homes guidelines was required, along with new energy and greenhouse gas savings assessments. Extensive analytical efforts were carried out to determine cost-effective levels of energy efficiency improvements over IECC that post-2005 ENERGY STAR qualified homes should be pegged to. As a result, in early 2006 EPA vetted its first major revisions to the ENERGY STAR Qualified Homes guidelines. The main features and innovations of the 2006 ENERGY STAR Qualified Homes guidelines that were adopted included:

- An energy savings goal of at least 15% over 2004 IECC or local code, whichever was more stringent. This was a relaxation of the previous 30% savings over 1993 MEC, and was necessitated by the increased stringency of the IECC over MEC, the NAECA-induced change in minimum air conditioner efficiency, and the inclusion of additional end-uses. In fact, due to the increase in minimum air conditioner efficiency and better required Solar Heat Gain Coefficients in the south, EPA's analysis found that it was much more difficult to attain energy savings over code in hot climates than in mixed and cold climates. In practice, this resulted in a bifurcation of the program requirements into two geographic regions:
  - A "hot" climate region, comprised of 2004 IECC climate zones 1, 2 & 3, within which a minimum 85 HERS index for label qualification was required (85 HERS index was a proxy for 15% site energy savings)
  - A "mixed" and "cold" climate region, comprised of 2004 IECC climate zones 4 through 8, within which a minimum 80 HERS index was required (80 HERS index was a proxy for 20% site energy savings)

- A much-simplified but all-encompassing National Builder Option Package (BOP) which featured:
  - 2004 IECC insulation levels
  - ENERGY STAR qualified HVAC equipment and ENERGY STAR qualified windows
  - A single simplified duct leakage specification (i.e., </= 4 cfm of duct leakage to the outside per 100 sq. ft. of conditioned floor area at 25 Pa pressurization of the distribution system)
  - A simpler and more easily-determinable set of climate-zone-specific infiltration specifications based on ACH50 (i.e., air changes per hour at 50 Pa pressure difference between house and ambient)
  - A requirement to include one category of ENERGY STAR qualified products

- The Thermal Bypass Checklist, an on-site visual inspection protocol for eliminating common thermal bypasses

- A requirement for HVAC equipment right-sizing using ACCA Manual J/S or equivalent calculations

As in the past, ENERGY STAR qualification continued to depend on achieving a fixed HERS index value despite an EPA proposal to replace the fixed numerical threshold with a dynamic one aligned with the HERS index value achieved by the National BOP for the same home. The EPA proposal was an attempt to eliminate HERS scoring variations arising from different fuels, geographic locations, house sizes, degree of attachment to other structures, and various other house construction parameters. This innovation, however, was ultimately not adopted in 2006.

The revised ENERGY STAR Qualified Homes guidelines were adopted and savings impacts determined, as shown in Exhibit 2. A detailed description of the assumptions and approach for determining the Version 2 impacts is delineated in reference 3.

**Exhibit 2: ENERGY STAR Qualified Home "Version 2" Annual Savings**

| Metric | 2005 Savings Assessment | 2006-2007 Savings Assessment | 2008 Savings Assessment |
|---|---|---|---|
| Electricity | 2,040 kWh | 2,262 kWh | 1,469 kWh |
| Natural Gas | 131 therms | 216 therms | 214 therms |
| Utility Bill | ~$295 | $376 | $393 |
| Greenhouse Gas Emissions | ~0.6 MTCe | 0.76 MTCe | 0.58 MTCe |
| **Analytic Parameter** | **Value** | **Value** | **Value** |
| Code Baseline | 2003/2004 IECC | 2003/2004 IECC | 2006 IECC |
| AC Baseline | 10 SEER | 10 SEER | 13 SEER |
| REM/Rate Version | 11.31 | 12.0 | 12.6 |
| Based on: | Average of 7 representative homes | Population-weighted average of 7 representative homes | Population-weighted average of 10 representative homes |

Note that because utility rates and greenhouse gas emission factors change over time, the utility bills and greenhouse gas emissions shown in these tables are for the year(s) the calculations were made. National average utility rates and emission factors were used, though these are known to vary regionally.

## 2011: ENERGY STAR Qualified Homes Guidelines "Version 3"

Analysis and field observations over a decade of implementing the ENERGY STAR Qualified Homes program resulted in brainstorming in the 2006-08 interval which uncovered several previously untapped opportunities for major increases in energy and greenhouse gas emission savings for the program. In many respects, these measures are simply often-overlooked good building science practices. The key measures proposed for the 2011 ENERGY STAR Qualified Homes program are as follows:

### Key Feature 1: Quality Control of Installation/Commissioning

Despite increases in the "nameplate" or "nominal" performance indices of insulation levels (i.e., R-value) and HVAC equipment (i.e., SEER, HSPF, AFUE), poor quality installation and commissioning often occurs, which does not allow the full potential of those nameplate values to be achieved. Common examples of poor installation and commissioning practices include:

- Insulation with voids, gaps, compression and lack of alignment between the air barrier and thermal surfaces, producing convective and conductive bypasses that seriously compromise effective insulating value
- High framing factors that allow parallel-path thermal bypasses through uninsulated studs
- Air conditioning units with significant over-sizing, improper refrigerant charge, and incorrect air-flow across the coil that significantly degrades the real-world performance of the unit
- Furnaces, heat pumps, and air-conditioners coupled with duct systems that are leaky, inadequately insulated, and with high pressure drops that significantly impair the delivery of heating and cooling energy to their intended destination

Even though quality control of installation and commissioning is often embodied *in writing* in residential energy codes, real world observations indicate that it is often not being enforced or adequately inspected for. This could be due to code inspectors' lack of training, budgetary constraints, or indifference. Regardless of cause, the lack of proper installation and commissioning also impacts the delivery of ENERGY STAR qualified homes that meet expected performance levels.

To address concerns with proper installation and commissioning, the 2011 guidelines integrate additional third-party-verified quality control checklists, which now include the following: **Thermal Bypass Inspection**, **Framing Quality**, **HVAC Quality Installation for Contractors** and **HVAC Quality Installation for Raters**. Enforcement will be carried out primarily by Raters though, in some instances, builders and contractors may complete certain quality assurance activities with oversight from Raters. Analysis reveals that significant additional real-world energy savings are possible with implementation of these checklists, which are not often recognized by residential energy simulations. To ensure a better level of comfort, adequate indoor air quality, and improved durability through management of bulk moisture, EPA has also developed an **Indoor Air Quality** checklist and **Water-Managed Construction** checklist.

**Key Feature 2: Hot Water Delivery Efficiency**

A renewed focus is also being placed on the reduction of hot water heating loads, which in the prior two iterations of the guidelines have only been incrementally addressed with nominal improvements in the energy factor of water heaters. Research indicates that large increases in ***effective*** energy factors would result from the following measures:

- Hot water conservation measures (e.g., low-flow showerheads, ENERGY STAR qualified clothes washers, ENERGY STAR qualified dishwashers)
- Efficient hot water distribution systems that use one of the following strategies:
  - Structured Plumbing
  - Manifold Layouts
  - Demand Controlled Pumping Systems

Because of the cost-effectiveness of these measures and the large lost-opportunity cost, these measures are becoming mandatory requirements in the 2011 guidelines.

**Key Feature 3: More Efficient Lighting and Appliances**

To further address savings available from lighting and plug-loads and promote integration with other ENERGY STAR qualified products, the 2011 guidelines will now require that all major consumer appliances (e.g., dishwasher, refrigerator, clothes washer), bathroom exhaust fans, and ceiling fans installed during construction of the home be ENERGY STAR qualified. In addition, EPA will require the adoption of either the Advanced Lighting Package (ALP), which requires a minimum of 60% of all hardwired fixtures to be ENERGY STAR qualified, or the use of 80% screw-in ENERGY STAR qualified CFLs. These measures are also becoming mandatory requirements in the 2011 guidelines.

**Key Feature 4: Improving the Equivalence Between the Performance and Prescriptive Paths & Improving Adoption of Market-Transforming Technologies and Practices**

Throughout the tenure of the ENERGY STAR Qualified Homes program the requirement to achieve a <u>fixed</u> HERS index value for qualification has produced some challenges. Under the current guidelines, a home can be configured with a given set of energy efficiency measures that result in the required HERS index of 80 in mixed/cold climate zones or 85 in hot climate zones. Then, keeping the energy efficiency measures constant, but simply changing one or more design features, the HERS index could be made to vary significantly. Such design features, which are largely not influenced by the ENERGY STAR Qualified Homes program, include:

- Space heating fuel (e.g., gas, oil and electric)
- Water heating fuel (e.g., gas, oil and electric)
- House size and dimensions
- Degree of attachment to other structures (i.e., single-family detached vs. multi-family)
- Geographic locations within the same climate zone, or across a nearby climate zone boundary
- Foundation construction (e.g., basement, crawl space, slab-on-grade)
- Number of bedrooms
- Number of stories

Given a constant set of energy efficiency features, these design features can alter the HERS index up to several points for individual factors and greater than 15 points by combining several factors into configurations often encountered in the real world. As a result, a home could be thrown significantly in or out of program compliance without changing any energy efficiency measures promoted by the ENERGY STAR Qualified Homes program. While the design features do legitimately impact the energy consumption of a home and cause a resulting shift in HERS index, this phenomenon presents a unique challenge for the ENERGY STAR Qualified Homes program. The market transformation goal of the program is to recognize and reward builders that have changed their building practices relative to non-participants to create high-quality energy efficient homes, thereby creating value in the marketplace for qualified homes. When partners achieve a fixed HERS index value by leveraging design features that are generally not influenced by the program, such as those listed above, the energy efficiency improvements between qualified and non-qualified homes can be minimized, making it difficult to recognize homes that are meaningfully more efficient. For example, if a large two-story basement home in a cold climate can qualify with significantly fewer improvements than a smaller single-story slab on grade home next door, this presents a challenge to qualifying homes that are meaningfully more efficient.

With the 2011 ENERGY STAR Qualified Homes guidelines, this challenge is addressed with a change in how EPA defines its performance path threshold for ENERGY STAR qualification. In place of a fixed value, the solution is to set the

HERS index threshold required for ENERGY STAR qualification at the same value that the same house would earn if configured to the ENERGY STAR prescriptive path, which is now referred to as the ENERGY STAR Reference Design. A detailed description of this challenge and its resolution is outlined in reference 5.

With this approach there are many positive ramifications for the ENERGY STAR Qualified Homes program:

- Eliminates the problems, delineated above, associated with disparities in HERS scores caused by differences in the design features
- Automatically "levels the playing field" with respect to house size (i.e., removes the current advantage that larger homes have in meeting ENERGY STAR Qualified Homes guidelines)
- Enables the program to achieve true parity between the performance path and the prescriptive bundle of real-world, cost-effective ENERGY STAR qualified equipment and products identified in the ENERGY STAR Reference Design
- Allows the ENERGY STAR HERS index target to automatically adapt to changes in:
    - The HERS Reference Home
    - The HERS algorithms
    - The ENERGY STAR Qualified Homes prescriptive path
- More accurately assesses and credits the savings associated with the energy efficiency features adopted by partners for compliance, rather than ascribing savings from inherent design features not targeted by the program

Note that this change in policy only defines a rated home that determines the performance threshold for the ENERGY STAR Qualified Homes program. As a result, the 2011 ENERGY STAR Qualified Homes guidelines continue to fully utilize, embrace and support:

- Use of the HERS algorithms as developed and approved by RESNET
- Use of the HERS Reference Home as developed and approved by RESNET
- Use of RESNET-approved residential energy software
- Use of the network of RESNET home energy raters to determine compliance with the performance path and complete crucial quality control activities in the field for both the performance and prescriptive path

**Key Feature 5: Addressing Absolute House Size and Carbon Footprint**

One of the advantages of the revised definition for the performance path, cited above, is to automatically "level the playing field" with respect to house size, taking away a "per-square-foot" performance bias for large homes. EPA has further addressed house-size considerations in the 2011 guidelines by more carefully considering the large absolute energy usage of large homes.

With Versions 1 & 2 of the guidelines, a 5,500 sq. ft. home could qualify for ENERGY STAR more easily than a similarly constructed 1,500 sq. ft. home, even though it might use and emit more than triple the absolute energy and greenhouse gas emissions. In fact, the larger home could actually use fewer energy efficiency measures than the smaller home and still achieve an equivalent HERS index. Though the revised performance path eliminates the incentive to build a larger home to ease compliance with the program, the larger home could still qualify for the label as easily as the smaller house.

After careful consideration EPA has decided to adopt a deliberate policy to "reward appropriate smallness" and "penalize wasteful largeness". To accomplish this, a decreased HERS index will be required for homes larger than the average size new home currently being built with the same number of bedrooms. In other words it will be necessary to achieve a more stringent HERS index threshold for ENERGY STAR qualification for larger-than-average homes.

For a given quantity of bedrooms, a home with conditioned floor area (CFA) that matches the approximate average size being constructed today is referred to as the Benchmark Home. The CFA of the benchmark home is shown in Exhibit 3.

**Exhibit 3: Conditioned Floor Area of Benchmark Home for Given Quantity of Bedrooms[2]**

| Bedrooms in Home to be Built | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| CFA of Benchmark Home [square feet] | 1,000 | 1,600 | 2,200 | 2,800 | 3,400 | 4,000 | 4,600 | 5,200 |

For homes larger than the benchmark home, the required HERS index value for ENERGY STAR qualification is made

[2] The 3 bedroom house size is approximated from U.S. Census data published in 2006. Conditioned floor area values as a function of the quantity of bedrooms was modified from Table 4, LEED for Homes Reference Guide, 1st edition, 2008.

more stringent (i.e., decreased) by multiplying that value by the following factor:

$$\text{Size Adjustment Factor} = [\text{CFA of Benchmark Home} / \text{CFA of Rated Home}]^{0.25}$$

The methodology used to arrive at this equation is described in detail in reference 5. Various values were considered for the scaling factor, "n", in place of 0.25, such as using a value that ensured that the annual "carbon footprint" of a larger home did not exceed the carbon footprint of the average size home. After considerable thought, however, and taking into consideration the fact that n could be adjusted for future versions of ENERGY STAR guidelines, a less aggressive approach was taken. The value selected limits the increase in the carbon footprint of larger homes to a rate roughly halfway between applying no factor at all (i.e., n=0) and applying a factor that would result in a carbon footprint equal to the average sized home. The value of n that will approximately accomplish this goal is 0.25.

There are two conditions to be met regarding achievement of the resulting HERS index value for larger homes:

1. The HERS index of the ENERGY STAR Reference Design Home must be achieved without the use of renewable energy
2. The additional reduction in HERS index imposed by the application of the size adjustment factor can be met by any combination of conservation measures and also the use of onsite renewable energy (e.g., solar).

The final rule set for determining the ENERGY STAR HERS Index Target value, which defines the maximum allowed HERS index to earn the ENERGY STAR is defined as follows:

A. For homes equal or smaller than the Benchmark Home:

***ENERGY STAR HERS Index Target = HERS Index of ENERGY STAR Reference Design Home***

B. For homes larger than the Benchmark Home:

***ENERGY STAR HERS Index Target = HERS Index of ENERGY STAR Reference Design Home x Size Adjustment Factor***

Where:

- The ENERGY STAR Reference Design Home essentially equals the home being rated, but configured with the requirements of the ENERGY STAR Reference Design (which incorporates state energy code requirements that are more rigorous than those specified in national ENERGY STAR Reference Design, if any). The full rule set for configuring the ENERGY STAR Reference Design Home is contained in Appendix A.
- The size adjustment factor is the equation noted on the prior page.

**Estimating Real-World Savings for the 2011 ENERGY STAR Qualified Homes Guidelines**

Gauging and taking credit for the anticipated savings from the 2011 guidelines presented a challenge in two regards:

- REM/Rate does not currently allow direct specification of some of the features (e.g., efficient hot water distribution systems)
- The "base case" assumptions for the HERS Reference Home often represent higher quality control (e.g., Level I insulation installation, 100% operating efficiency for HVAC equipment) than is known to occur in the real world on a consistent basis.

The second challenge is a concern because stakeholders often associate the savings of an ENERGY STAR qualified home purely with its HERS index, when in fact the HERS metric is not intended to be a reflection of average real-world savings, but instead a consistent and uniform method for assessing the efficiency of a home relative to a standard baseline. As a result, the correlation between HERS index and real-world savings for an ENERGY STAR qualified home is partly dependent on whether the specifications of the standard HERS Reference Home reflect a standard new home constructed today.

For example, when modeling an ENERGY STAR qualified home under the 2011 guidelines, it was assumed that insulation would be installed to "Grade I" standards, as defined in the RESNET guidelines, because this is a mandatory requirement of the 2011 guidelines and is further ensured with the completion of the Thermal Bypass Checklist. At the same time, the HERS Reference Home is also assumed to have insulation installation to "Grade I" standards. The difference in the energy consumption of the two simulated homes is the purported relative savings of the ENERGY STAR qualified home over "code." However, is this high-quality insulation installation actually true for most real-world "code" homes? Extensive field observations over more than a decade by EPA staff and many building scientists have concluded that they are not and that the savings are therefore being underestimated. This presented a challenge when estimating real-world savings resulting from the 2011 ENERGY STAR Qualified Homes guidelines. Were savings attributable to the program to be based on the HERS index alone as predicted by the computer simulations, which might have given an unearned advantage to “code” homes, or were the “code” homes to be “adjusted” to account for real world construction?

For purposes of EPA’s internal programmatic projections of typical real-world savings of 2011 ENERGY STAR qualified homes, the baseline was initially aligned with the HERS Reference Home, but where supporting evidence suggested standard practice below that required by code, the characteristics were downgraded to match real-world observations. Estimated energy savings based on this approach should better reflect the savings that might be achieved in the field.

Therefore, to address these concerns, the following process was used:

- First, ten ENERGY STAR Qualified Home genotypes were designed, representing typical climates, population weighting, and construction techniques. The attributes of these homes are described in detail in the Appendix.

- Second, a standard HERS rating simulation was completed using REM/Rate 12.6 for each of these representative homes. Each rated home was configured with all of the mandatory requirements and features of the ENERGY STAR Reference Design that could be entered into REM/Rate using standard input fields. For both the ENERGY STAR Reference Design and HERS Reference Home the following resulting values were tabulated, broken down by end-use and, where necessary, by building element (e.g., above-grade walls, ceiling, infiltration, duct leakage):
  - Electricity and natural gas energy consumption and utility bill costs
  - Heating and cooling design and annual loads

- Next, a series of Improvement Factors emanating from the 2011 ENERGY STAR Qualified Homes Guidelines Quality Control Checklists (e.g., HVAC Quality Installation, Quality Framing, Thermal Bypass Inspection) and mandatory water efficiency measures were developed as delineated in Exhibit 4. Some of these were determined with parametric simulations of the ENERGY STAR Reference Home with and without various features; and some were estimated independently using engineering equations. To arrive at final real-world savings numbers, the appropriate energy budget elements (i.e., consumption, design & annual loads, utility bill costs) obtained from the REM/Rate outputs were modified by these Improvement Factors, taking care to:
  - Not double-count
  - Take synergistic effects into account (e.g., if a cooling load was reduced then the cooling energy consumption reduction due to a more efficient duct system would need to be calculated with regard to this reduced load)
  - Apply the factor only to the appropriate end-use (e.g., heating, cooling), building element (e.g., above-grade walls, ceiling), and/or energy budget element (e.g., load or consumption)

All improvement factors are summarized in Exhibit 4 and were applied in multiplicative fashion to prevent double-counting. Measures not listed in this exhibit were modeled using standard REM/Rate input fields.

**Exhibit 4: Summary of Improvement Factors for Mandatory Requirements, Including Checklists**

| Relevant Checklist | Measure(s) | Improvement Factor |
|---|---|---|
| Thermal Bypass Checklist | Minimized thermal bypasses in envelope using complete air-barrier detail aligned with insulation | Improvement factor defined as 15% reduction in heating and cooling loads, multiplied by the fraction of load from non-fenestration exterior surfaces to that of total load[3]. |
| | Mandatory Grade I insulation | Each rated home was run with Grade III insulation in walls and floors and Grade II in ceilings, then re-run with Grade I insulation in all components. The improvement factor was then developed from the ratio of the resulting design loads, annual loads, and energy consumption of the improved versus unimproved homes. The results were used to reduce the energy loads and consumption of the ENERGY STAR Reference Design Home with Grade I insulation. |
| Quality Framing Checklist | Use of OVE details or advanced technology to reduce framing fraction in walls; use of raised-heel truss and raised HVAC platform to reduce ceiling framing fraction | No improvement factor was developed for this checklist. Instead, framing fractions were reduced below HERS-default values and modeled directly in REM/Rate for the rated home. The framing fraction was estimated to improve from 23% to 17% for walls and from 11% to 7% for ceilings. |
| HVAC Quality Installation[4] | Right-sizing; TXV or proper refrigerant charge for vapor-compression equipment; proper air flow over coils and heat exchangers | For combustion heating systems, improvement factor defined as 10% reduction in heating consumption to account for right-sizing. For electric vapor compression heating and cooling systems, improvement factor defined as 19% reduction in consumption to account for both right-sizing and proper refrigerant charge. |
| | Higher duct system distribution efficiency from ACCA Manual D & T compliance, measures to ensure pressure-balancing, and visual inspection to prevent poor installation | Improvement factor of 15%, equating to improved duct leakage value from 4.0 to of 3.4 CFM per 100 square feet of CFA, which was entered into REM/Rate. |
| Indoor Air Quality Checklist | Whole-house ventilation, local exhaust, effective air filtration | No improvement factor applied. Increased energy consumption from ventilation captured through standard REM/Rate input fields. |
| Water Managed Construction Checklist | Water-managed foundation, walls, and roof; use of moisture resistant or moisture protected materials | No improvement factor applied, as no energy impact from this checklist is anticipated. |
| Mandatory ENERGY STAR Qualified Lighting | Advanced Lighting Package or 80% ENERGY STAR Qualified CFLs | No improvement factor applied; instead 80% fluorescent hard-wired fixtures were modeled directly in REM/Rate for the rated homes. |

[3] This estimate is primarily based upon a study by Swanson, Colby, et al*; Advanced Energy Corporation; 2005; Measuring the Public Benefit from Energy Efficient Homes*. This study analyzed ~7,000 new homes constructed between 2003 and 2004 for their energy performance. This included almost 3,000 baseline homes, which averaged around 20% better efficiency than the 1993 MEC, the basis for estimating ENERGY STAR savings at that time; almost 3,000 ENERGY STAR Homes constructed in the same period under the "Version 1" guidelines; and over 800 Guaranteed Performance Homes, which included measures beyond ENERGY STAR guidelines that were largely analogous to the subsequent Thermal Bypass Checklist. This study revealed that the implementation of the thermal bypass checklist measures engendered ~20% summer/cooling intensity reduction over ENERGY STAR homes that did not incorporate these measures.

[4] This estimate is primarily based upon a paper by Chinery, Glenn; EPA; 2004; *Typical Real-World Performance Degradation of Heat Pumps and Air Conditioners Installed in Residences and Potential Energy Savings Due to Correcting Problems*. This paper is a compilation of findings from a number of studies which measured typical real-world HVAC equipment degradation and found ~10% degradation due to over-sizing, ~12% degradation due to refrigerant mischarge, ~10% degradation due to inadequate air flow over heating and cooling coils, and ~15% degradation due to duct losses.

| | | |
|---|---|---|
| Mandatory ENERGY STAR Qualified Products | When major consumer appliances are installed, they must be ENERGY STAR qualified | No improvement factor applied. Instead, products were modeled directly in REM/rate, including a refrigerator (456 kWh) and a dishwasher (0.65 EF). No savings were estimated for clothes washers and ceiling fans were not assumed to be present in the homes. |
| Mandatory Water Efficiency Measures | Efficient hot water distribution system (e.g., manifold, structured plumbing, demand-controlled pumping); low-flow shower-heads | Using engineering calculations, improvement factor defined as a 24% reduction in consumption for gas water heaters and 31% reduction for electric water heaters. |

The differences in energy use (i.e., electrical kWh and natural gas therms) between the HERS reference homes and the ENERGY STAR Reference Design Homes modified with the Improvement Factors were then combined into a weighted-average savings value. The kWh and therm energy savings were also translated into equivalent site, source, greenhouse gas emissions, and utility bill savings. The emissions factors used are described in more detail in Appendix A. National average utility rates were determined from EIA projections. With this approach, the national average savings were calculated for the 2011 ENERGY STAR Qualified Homes program, inclusive of improvement factors, using 2009 national average utility rates and greenhouse gas emission factors. These savings are shown in Exhibit 5.

**Exhibit 5: ENERGY STAR Qualified Home "Version 3" Annual Savings**

| Metric | Savings Assessment |
|---|---|
| Electricity | 1,644 kWh |
| Natural Gas | 260 therms |
| Utility Bill | $481 |
| Greenhouse Gas Emissions | 0.66 MTCe |
| **Analytical Parameter** | **Value** |
| Code Baseline | 2006 IECC |
| AC Baseline | 13 SEER |
| REM/Rate version | 12.6 |
| Based on: | Population-weighted average of 10 representative homes |

In order to validate this approach to determining real-world savings, EPA is currently pursuing an evaluation project to correlate real-world savings with HERS residential software simulation predictions. A statistically-significant population of rated homes in a particular climate zone has been selected and the real-world energy bills, actual weather data, and full REM/Rate files used to qualify the homes are being analyzed. This analysis is expected to provide a defensible correlation of predicted versus real-world savings for the ENERGY STAR Qualified Homes Program.

## Appendix Notes on Assumptions and Methodology

### A. Characteristics of Simulated Homes

As mentioned, a series of representative baseline homes were developed from which to measure savings.

There are significant regional variations in house construction types (e.g., basement, crawl space or slab-on-grade foundations; number of stories) and building practices across the country due to differences in climate; state and local building codes and their degree of enforcement; local energy costs; and traditions and trends.

The energy use and emissions of any house is also a function of the choice of fuels (e.g., electricity, natural gas, oil), which depends on their availability, cost and homeowner preference; individual house size, which can typically range from less than 1,000 to more than 4,000 square feet; the ratio of window area to floor area (WFA), which typically ranges from <12% to >20% of conditioned floor area; and window orientation with respect to the sun. These factors directly influence loads, as do the number of occupants, which is assumed to correlate with number of bedrooms, and occupant lifestyles.

For this analysis, "representative" baseline homes were developed by using a diversified set of 9 geographic regions[5], with the home in each region configured with the predominant number of stories, foundation construction type, and fuel type found in each region as ascertained by EIA's Residential Energy Consumption Survey. Other house construction parameters included 18% WFA and an equal distribution of windows on all sides of the house, which are consistent with the reference home assumptions used within the HERS guidelines.

Regarding house size, an approximate national average was used for all homes. U.S. Census data revealed that the median U.S. house floor area for homes built in the mid 1990's was a little under 2,000 sq. ft.; that if larger-house-trends continued, homes would be >2,000 sq. ft. by the turn of the century; and would continue to increase after that. Based on various current sources in the literature (e.g., U.S. Census data, National Association of Home Builders) 2,200 square feet of conditioned floor area in a 3-bedroom home was used for this analysis. The detailed development of these numbers is covered in reference 5.

The parameters modeled for each of the representative homes are tabulated in the two tables below.

**Geographic / Climate Characteristics of Representative Homes**

| Climate | Cold/ Extreme | Mixed/ Dry | Mixed/ Moist | Marine | Hot/ Dry | Warm/ Humid | Hot/ Humid | Mixed/ Dry | Warm/ Humid | Cold |
|---|---|---|---|---|---|---|---|---|---|---|
| IECC 2006 Climate Zone | 6 | 3 | 4 | 4 | 2 | 2 | 1 | 3 | 3 | 5 |
| City | Minnea-polis MN | Las Vegas NV | Lexington KY | Seattle WA | Phoenix AZ | Orlando FL | Miami FL | Las Vegas NV | Atlanta GA | Chicago IL |
| Latitude (Degrees N) | 45 | 36 | 38 | 48 | 34 | 29 | 26 | 36 | 34 | 42 |
| "V" of Passive Solar H/V Ratio | 2.2 | 3.3 | 3.0 | 2.0 | 3.7 | 5.5 | 7.7 | 3.3 | 3.7 | 2.5 |
| Heating Degree Days (HDD65) | 8,010 | 2,535 | 4,819 | 5,122 | 1,444 | 660 | 98 | 2,535 | 3,025 | 6,183 |
| Cooling Degree Hours (CDH74) | 6,806 | 43,153 | 11,208 | 1,050 | 54,404 | 33,985 | 39,401 | 43,153 | 16,803 | 9,736 |
| ASHRAE W-factor | 0.97 | 0.81 | 0.80 | 0.85 | 0.68 | 0.73 | 0.69 | 0.81 | 0.74 | 0.93 |
| Design Heating Temperature ($^oF$) | -12 | 28 | 8 | 26 | 34 | 38 | 47 | 28 | 24 | 1 |
| Design Cooling Temperature ($^oF$) | 89 | 106 | 91 | 82 | 107 | 93 | 90 | 106 | 92 | 89 |
| ZIP Code | 554 | 890 | 405 | 981 | 850 | 328 | 330 | 890 | 303 | 606 |
| Estimated Population Fraction | 10% | 5% | 20% | 10% | 10% | 10% | 10% | 5% | 10% | 10% |

[5]These 10 sites and homes were not intended to be a rigorously statistically accurate average all new U.S. construction - but sufficiently representative for case studies of typical homes when evaluating changes in program parameters.

## Housing Characteristics of Representative Homes

| House Type | Colonial | Colonial | Colonial | Colonial | Ranch | Ranch | Ranch | Colonial | Ranch | Colonial |
|---|---|---|---|---|---|---|---|---|---|---|
| **Above-Grade Stories** | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 2 |
| **Conditioned Levels** | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 3 |
| **Foundation Type** | Cond. Bsmt | Slab | Uncond. Bsmt | Vented Crawl | Slab | Vented Crawl | Slab | Slab | Vented Crawl | Cond. Bsmt |
| **Conditioned Floor Area** | 2,200 | 2,200 | 2,200 | 2,200 | 2,200 | 2,200 | 2,200 | 2,200 | 2,200 | 2,200 |
| **Footprint Depth (ft)** | 21.6 | 26.0 | 27.5 | 27.5 | 40.0 | 40.0 | 40.0 | 26.0 | 40.0 | 21.6 |
| **Footprint Width (ft)** | 34.0 | 42.3 | 40.0 | 40.0 | 55.0 | 55.0 | 55.0 | 42.3 | 55.0 | 34.0 |
| **Footprint Area ($ft^2$)** | 733 | 1,100 | 1,100 | 1,100 | 2,200 | 2,200 | 2,200 | 1,100 | 2,200 | 733 |
| **Perimeter (ft)** | 111 | 137 | 135 | 135 | 190 | 190 | 190 | 137 | 190 | 111 |
| **Above-Grade Wall Height (ft)** | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| **Basement Wall Height (ft)** | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| **Above-Grade Wall Area ($ft^2$]** | 2,000 | 2,459 | 2,430 | 2,430 | 1,710 | 1,710 | 1.710 | 2,459 | 1,710 | 2,000 |
| **Below-Grade Wall Area ($ft^2$)** | 889 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 889 |
| **Conditioned Space Volume ($ft^3$)** | 19,067 | 19,800 | 19,800 | 19,800 | 19,800 | 19,800 | 19,800 | 19,800 | 19,800 | 19,067 |
| **Window Area Per Wall ($ft^2$)** | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 |
| **WFA [%]** | 18% | 18% | 18% | 18% | 18% | 18% | 18% | 18% | 18% | 18% |
| **Number of Bedrooms** | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Space & Water Heating Fuel** | Gas | Elec. | Gas | Gas | Elec. | Elec. | Elec. | Gas | Gas | Gas |

For additional clarification, the following table shows the rule-set proposed in the 2011 ENERGY STAR Qualified Homes guidelines for configuring the ENERGY STAR Reference Design. For illustrative purposes, the RESNET rule set used to configure the HERS Reference Home and rated home are also included.

## Rule Set Used to Configure ENERGY STAR Reference Design Home & Energy Efficiency Features of Representative Homes

| Building Component | HERS Reference Home | HERS Rated Home | ENERGY STAR Reference Design Home |
|---|---|---|---|
| Above-Grade Walls: | Type: Wood frame | Same as Rated Home | Type: Wood frame, with 17% framing fraction |
| | Gross Area: Same as Rated Home | Same as Rated Home | Same as Rated Home |
| | U-Factor: From RESNET Table 303.4.1(2) | Same as Rated Home | Wood frame wall R-values from 2009 IECC, Table 402.1.1; assuming Grade I installation |
| | Solar absorptance = 0.75 | Same as Rated Home | Same as Rated Home |
| | Emittance = 0.90 | Same as Rated Home | Same as Rated Home |
| Conditioned Basement Walls: | Type: Same as Rated Home | Same as Rated Home | Same as Rated Home |
| | Gross Area: Same as Rated Home | Same as Rated Home | Same as Rated Home |
| | U-Factor: From RESNET Table 303.4.1(2) with the insulation layer on the interior side of walls | Same as Rated Home | Basement Wall R-values from 2009 IECC, Table 402.1.1; Assuming Grade I installation and with insulation layer on the interior side of walls |
| Floors Over Unconditioned Spaces: | Type: Wood frame | Same as Rated Home | Type: Wood frame |
| | Gross Area: Same as Rated Home | Same as Rated Home | Same as Rated Home |
| | U-Factor: From RESNET Table 303.4.1(2) | Same as Rated Home | Floor R-values from 2009 IECC, Table 402.1.1; Assuming Grade I installation |
| Ceilings: | Type: Wood frame | Same as Rated Home | Type: Wood frame, with 7% framing fraction |
| | Gross Area: Same as Rated Home | Same as Rated Home | Same as Rated Home |
| | U-Factor: From RESNET Table 303.4.1(2) | Same as Rated Home | Ceiling R-values from 2009 IECC, Table 402.1.1; Assuming Grade I installation |
| Roofs: | Type: Composition shingle on wood sheathing | Same as Rated Home | Type: Composition shingle on wood sheathing |
| | Gross Area: Same as Rated Home | Same as Rated Home | Same as Rated Home |
| | Solar Absorptance = 0.75 | Values from Table RESNET 303.4.1.(4)[1] | Solar Absorptance = 0.92 |
| | Emittance = 0.90 | Emittance values provided by the roofing manufacturer, when available[2] | Emittance = 0.90 |
| Attics: | Type: Vented with aperture = 1ft² per 300 ft² ceiling area | Same as Rated Home | Type: Vented with aperture = 1ft² per 300 ft² ceiling area<br>Radiant Barrier: In climate zones 1-3, if ≥ 10 linear ft of ductwork are located in unconditioned attic, then a radiant barrier shall be installed |
| Foundations: | Type: Same as Rated Home | Same as Rated Home | Same as Rated Home |
| | Gross Area: Same as Rated Home | Same as Rated Home | Same as Rated Home |
| | U-Factor / R-value: From RESNET Table 303.4.1(2) | Same as Rated Home | Slab Wall R-values and Slab Depth from 2009 IECC, Table 402.1.1; as appropriate; Assuming Grade I installation |
| Crawlspaces: | Type: Vented with net free vent aperture = 1ft² per 150 ft² of crawlspace floor area | Same as the Rated Home[3] | Type: Vented with net free vent aperture = 1ft² per 150 ft² of crawlspace floor area |
| | U-factor: From RESNET Table 303.4.1(2) for floors over unconditioned spaces. | Same as Rated Home | Floor R-values from 2009 IECC, Table 402.1.1, Assuming Grade I installation |
| Doors: | Area: 40 ft² | Same as Rated Home | Same as Rated Home |
| | Orientation: North | Same as Rated Home | Same as Rated Home |

| | | | |
|---|---|---|---|
| | U-factor: Same as fenestration from RESNET Table 303.4.1(2) | Same as Rated Home | ENERGY STAR qualified doors |
| Glazing: | Total Area = 18% of conditioned floor area | Same as Rated Home | Total Area = 18% of conditioned floor area [4] |
| | Orientation: Equally distributed to four (4) cardinal compass orientations (N, E, S, & W) | Same as Rated Home | Orientation: Equally distributed to four (4) cardinal compass orientations (N, E, S, & W) |
| | U-factor: From RESNET Table 303.4.1(2) | Same as Rated Home | ENERGY STAR Qualified Windows except as follows:<br>CZ 2: U-value ≤ 0.55<br>CZ 4: U-value ≤ 0.40 |
| | SHGC: From RESNET Table 303.4.1(2) | Same as Rated Home | ENERGY STAR Qualified Windows except as follows:<br>CZ 2: SHGC ≤ 0.35<br>CZ 4: SHGC ≤ 0.45 |
| | Interior shade coefficient: Summer = 0.70 Winter = 0.85 | Same as HERS Reference Home | Same as HERS Reference Home |
| | External Shading: None | Same as Rated Home | External Shading: None |
| Skylights: | None | Same as Rated Home | None |
| Thermally Isolated Sunrooms: | None | Same as Rated Home | None |
| Air Exchange Rate: | Specific Leakage Area (SLA) = 0.00048 (assuming no energy recovery) | For residences that are not tested, the same as the HERS Reference Home<br>For residences without mechanical ventilation systems that are tested in accordance with ASHRAE Standard 119, Section 5.1, the measured air exchange rate but not less than 0.35 ach<br>For residences with mechanical ventilation systems that are tested in accordance with ASHRAE Standard 119, Section 5.1, the measured air exchange rate combined with the mechanical ventilation rate, which shall not be less than 0.01 x CFA + 7.5 x (Nbr+1) cfm | Measured air exchange rate as follows:<br>CZ 1-2: 7 ACH50;<br>CZ 3-4: 6 ACH50<br>CZ 5-7: 5 ACH50;<br>CZ 8: 4 ACH50<br><br>Assuming continuously operating mechanical ventilation system with a delivered ventilation rate compliant with ASHRAE 62.2, 2007, Section 4.4. |
| Mechanical Ventilation: | None, except where a mechanical ventilation system is specified by the Rated Home, in which case: Annual vent fan energy use: kWh/yr = 0.03942*CFA + 29.565*(Nbr+1) (per dwelling unit) where: CFA = conditioned floor area Nbr = number of bedrooms | Same as Rated Home | Mechanical ventilation system with annual vent fan energy use: kWh/yr = 0.03942*CFA + 29.565*(Nbr+1) (per dwelling unit) where:<br>CFA = conditioned floor area<br>Nbr = number of bedrooms |
| Internal Gains: | IGain = 17,900 + 23.8*CFA + 4104*Nbr (Btu/day per dwelling unit) | Same as HERS Reference Home, except as provided by RESNET Section 303.4.1.7. | Same as HERS Reference Home, except as provided by RESNET Section 303.4.1.7, assuming 80% fluorescent lighting, mechanical ventilation system fan, ENERGY STAR qualified refrigerator, dishwasher, and ceiling fans |

| | | | |
|---|---|---|---|
| Internal Mass: | An internal mass for furniture and contents of 8 pounds per square foot of floor area | Same as HERS Reference Home, plus any additional mass specifically designed as a Thermal Storage Element but not integral to the building envelope or structure | An internal mass for furniture and contents of 8 pounds per square foot of floor area |
| Structural Mass: | For masonry floor slabs, 80% of floor area covered by R-2 carpet and pad, and 20% of floor directly exposed to room air | Same as Rated Home | For masonry floor slabs, 80% of floor area covered by R-2 carpet and pad, and 20% of floor directly exposed to room air |
| | For masonry basement walls, same as Rated Home, but with insulation required by RESNET Table 303.4.1(2) located on the interior side of the walls | Same as Rated Home | For masonry basement walls, same as Rated Home, but with basement wall R-values from 2009 IECC, Table 402.1.1; Assuming Grade I installation and with insulation layer on the interior side of walls |
| | For other walls, for ceilings, floors, and interior walls, wood frame construction | Same as Rated Home | For other walls, for ceilings, floors, and interior walls, wood frame construction |
| Heating Systems: | Fuel Type: Same as Rated Home | Same as Rated Home | Same as Rated Home |
| | Electric Efficiency: Air source heat pump with prevailing federal minimum efficiency | Same as Rated Home | CZ 1-3: 8.2 HSPF / 14.5 SEER / 12 EER ASHP<br>CZ 4-8: 8.5 HSPF / 14.5 SEER / 12 EER ASHP |
| | Non-electric Furnace Efficiency: Natural gas furnace with prevailing federal minimum efficiency | Same as Rated Home | CZ 1-3: 80 AFUE for all furnaces<br>CZ 4-8: 92 AFUE for gas furnaces<br>CZ 4-8: 85 AFUE for oil furnaces |
| | Non-electric Boiler Efficiency: Natural gas boiler with prevailing federal minimum efficiency | Same as Rated Home | CZ 1-3: 80 AFUE for all boilers<br>CZ 4-8: 85 AFUE for all boilers |
| | Capacity: Sized in accordance with Section 303.5.1.4 of the RESNET Standard. | Same as Rated Home | Capacity: Sized in accordance with Section 303.5.1.4 of the RESNET Standard. |
| Cooling Systems: | Fuel Type: Electric | Same as Rated Home | Same as Rated Home |
| | Efficiency: In accordance with prevailing federal minimum standards | Same as Rated Home | CZ 1-3: 14.5 SEER/12 EER AC, with sensible heat ratio = 0.70<br>CZ 4-8: 13 SEER AC |
| | Capacity: Sized in accordance with Section 303.5.1.4 of the RESNET Standard. | Same as Rated Home | Capacity: Sized in accordance with Section 303.5.1.4 of the RESNET Standard. |
| Service Water Heating Systems: | Fuel Type: Same as Rated Home | Same as Rated Home | Fuel Type: Same as Rated Home |
| | Efficiency: in accordance with prevailing federal minimum standards | Same as Rated Home | Efficiency: Gas - 0.61 EF; Electric - 0.92 EF |
| | Use (gal/day): 30*Ndu + 10*Nbr where Ndu = number of dwelling units | Same as HERS Reference Home | Same as HERS Reference Home |
| | Tank temperature: 120°F | Same as HERS Reference Home | Same as HERS Reference Home |
| Thermal Distribution Systems: | A thermal distribution system efficiency (DSE) of 0.80 shall be applied to both the heating and cooling system efficiencies. | As specified by RESNET Table 303.4.1(3), except when tested in accordance with ASHRAE Standard 152-2004, and then either calculated through hourly simulation or calculated in accordance with ASHRAE | Duct Leakage to Outside:<br>4 CFM/100 ft² of conditioned floor area<br>Duct Insulation:<br>Attic: R-8; Other Uncond. Spaces: R-6<br>Duct Surface Area: Same as Rated Home |

| | | | |
|---|---|---|---|
| | | Standard 152-2004 | Duct Location, Per # Stories & Foundation Type:<br>1-Story / Slab: 100% in Attic<br>2-Story / Slab: 75% in Attic; 25% in Cond. Space<br>1-Story / Crawl: 100% in Crawlspace<br>2-Story / Crawl: 75% in Crawl; 25% in Cond. Space<br>1-Story / Bsmt: 100% in Basement<br>2-Story / Bsmt: 75% in Bsmt; 25% in Cond. Space |
| Thermostat: | Type: Manual | Type: Same as Rated Home | Type: Programmable |
| | Temperature setpoints:<br>Cooling temperature set point = 78°F;<br>Heating temperature set point = 68°F | Temperature setpoints: Same as the HERS Reference Home, except as required by RESNET Section 303.5.1.2 | Temperature setpoints: Same as the HERS Reference Home, except as required by RESNET Section 303.5.1.2 |

Footnotes:

1. Except where test data are provided for roof surface in accordance with ASTM methods E-903, C-1549, E-1918, or CRRC Method # 1.
2. Emittance values provided by the roofing manufacturer in accordance with ASTM C-1371 shall be used when available. In cases where the appropriate data are not known, the value shall be the same as the Reference Home.
3. Same as the Rated Home, net free ventilation area shall not be less than the Reference Home unless an approved ground cover in accordance with IRC 408.1 is used, in which case, the net free ventilation area shall be the same as the Rated Home down to a minimum net free vent area of 1ft² per 1,500 ft² of crawlspace floor area.
4. For homes with conditioned basements and for multi-family attached homes the following formula shall be used to determine total window area:

$$AF = 0.18 \times AFL \times FA \times F$$

   Where:
   - AF = Total fenestration area
   - AFL = Total floor area of directly conditioned space
   - FA = (Above-grade thermal boundary gross wall area) / (above-grade boundary wall area + 0.5 x below-grade boundary wall area)
   - F = 1- 0.44* (Common Wall Area) / (above-grade thermal boundary wall area + common wall area)

   And where:
   - Thermal boundary wall is any wall that separates conditioned space from unconditioned space or ambient conditions;
   - Above-grade thermal boundary wall is any portion of a thermal boundary wall not in contact with soil;
   - Below-grade boundary wall is any portion of a thermal boundary wall in soil contact; and
   - Common wall is the total wall area of walls adjacent to another conditioned living unit, not including foundation walls.

## B. Emission Factors

Average per-house energy savings estimates were converted to other parameters using emissions factors. Emission factors for fuels and electricity generation were supplied by Lawrence Berkeley National Laboratory (LBNL) and the Cadmus Group, Inc. (see reference 4). These consisted of equivalent carbon (Ce), carbon dioxide ($CO_2$), nitrous oxides (NOx), and sulfur dioxide ($SO_2$) per combusted therm of gas and kilowatt-hour of electricity consumed at the house.

Emissions per therm of gas are known constants and have been published by LBNL and other researchers for years. The table below shows the factors for natural gas in grams of equivalent carbon (Ce), carbon dioxide ($CO_2$), nitrous oxides ($NO_x$) and sulfur dioxide ($SO_2$) per therm. A therm is 100,000 Btu and one Btu is the thermal energy required to raise the temperature of one pound of water one degree F.

**Natural Gas Emissions Factors**

| End-Use | Grams Ce / Therm | Grams $CO_2$ / Therm | Grams $NO_x$ / Therm | Grams $SO_2$ / Therm |
|---|---|---|---|---|
| Furnace | 1,445 | 5,299 | 4.147 | 0.00 |
| Water Heater | 1,445 | 5,299 | 5.562 | 0.00 |

Emissions per kWh vary by power plant, utility service territory, state, region and time of generation (e.g., season, time of day). Another important feature of the electrical emission factors is that they are predicted to decrease in future years due to increases in power plant efficiency, "cleaner" combustion, and generation mix changes. These changes over time were taken into account in the impact spreadsheets. The current set of electricity emission factors is derived from the *"Regional Electricity Emission Factors, Final Report*," November 16, 1998, prepared for the U.S. EPA by the Cadmus Group, Inc., and is shown below.

**Electricity $CO_2$ Emissions Factors**

| End-Use | Lbs $CO_2$ / kWh |
|---|---|
| 1997-2000 | 1.64 |
| 2001 | 1.55 |
| 2002 | 1.46 |
| 2003 | 1.37 |
| 2004 | 1.28 |
| 2005 | 1.20 |
| 2006 | 1.17 |
| 2007 | 1.15 |
| 2008 | 1.13 |
| 2009 | 1.11 |
| $\geq$ 2010 | 1.09 |

Nitrous oxide emissions vary from 0.3 - 3.9 grams of $NO_x$/kWh, depending on the region; with a national average amount of 2.20 grams $NO_x$/kWh. Sulfur dioxide emissions vary from 0.5 - 10.4 grams $SO_2$/kWh, depending on the region; the national average amount is 4.9 g-$SO_2$/kWh.

## References

1. Chinery, Glenn, “Penetration Goals for the ENERGY STAR for Homes Program: Chronology, Assumptions and Actual Curves”, internal EPA analysis, September 28, 2001.

2. Chinery, Glenn, “The Assumptions/Algorithms for Emission Savings Impacts”, internal EPA analysis, December 20, 2001.

3. Chinery, Glenn, “Code—>Energy Star Cost Effectiveness Study”, internal EPA analysis to assess the energy and carbon savings of 2006 ENERGY STAR qualified homes over 2004 IECC residential energy code, August 2005.

4. *“Regional Electricity Emission Factors, Final Report*,” November 16, 1998, prepared for the U.S. EPA by The Cadmus Group, Inc.

5. Chinery, Glenn, “ENERGY STAR for Homes Version 3 (2011): Performance Path HERS Scoring Label Qualification Criteria –Including Incorporation of House-Size Parameter”, internal EPA analysis, October 2008.