Energy and Buildings 80 (2014) 441–450

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Asset rating with the home energy scoring tool

Evan Mills[a,*], Norman J. Bourassa[a], Leo I. Rainer[a], Gregory Homan[a], Noel Merket[b], Danny Parker[c], Glenn Dickey[d], Joan Glickman[e]

[a] Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA
[b] National Renewable Energy Laboratory, 15013 Denver West Parkway, Golden, CO 80401, USA
[c] Florida Solar Energy Center, 1679 Clearlake Road, Cocoa, FL 32922, USA
[d] SRA International, 6003 Executive Boulevard, #400, Rockville, MD 20852, USA
[e] United States Department of Energy, 1000 Independence Avenue, SW, Washington, DC 20585, USA

ARTICLE INFO

Article history:
Received 13 February 2014
Received in revised form 24 May 2014
Accepted 28 May 2014
Available online 4 June 2014

Keywords:
Residential
Home rating
Validation

ABSTRACT

In 2010, as one of many energy initiatives within a broader economic stimulus program, the U.S. Department of Energy (DOE) and Lawrence Berkeley National Laboratory (LBNL) initiated development of a new web-based computer tool and method for providing an energy rating of existing single-family homes. The resulting Home Energy Scoring Tool is a key component of the DOE's Home Energy Score Program for residential building energy labeling, a voluntary national asset rating method that employs a simplified and standardized energy assessment process. The tool-development component of the program has been designed to support the energy audit marketplace by providing a substantially lower-cost, entry-level assessment method analogous to the fuel-economy ratings associated with vehicles. Averaged over a well-characterized sample of homes, the Home Energy Scoring tool is accurate to within 1% of mean weather-normalized energy bills (with 82% of homes having an absolute error of 25% or less), significantly better than two other popular methods known as SIMPLE and REM/Rate. This article presents technical details of the Home Energy Scoring Tool, and how it has evolved over time, including the calculation methodology, accuracy validation, and the web services feature that allows any qualified third-party software developer to integrate the methodology into their own web-based applications and market delivery strategy. As of April 2014, approximately 200 individuals had been qualified to deliver the assessments and had rated 10,600 homes in cooperation with 23 partner organizations across the United States.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Globally, energy used in the buildings sector is responsible for 11 billion metric tons per year of greenhouse-gas emissions, or about a third of all emissions from human activity [1]. The proportion is similar in the U.S., and corresponded to an energy bill of $431 billion in 2010, of which homes were responsible for $252 billion [2].

Recognizing the magnitude of residential energy use – and the potential for savings through enhanced energy efficiency – in 2010 the U.S. Department of Energy (DOE) tasked the Lawrence Berkeley National Laboratory (LBNL) to develop a new tool within the Home Energy Saver suite [3] (hes.lbl.gov, hespro.lbl.gov) to provide an "asset-based" analysis of energy performance for homeowners, buyers, and sellers of detached single-family and townhomes in the United States. The primary goal of an asset rating is to provide standardized energy assessment information – isolating the physical characteristics of the home from those of widely varying operational characteristics. The resulting Home Energy Scoring Tool ("Scoring Tool") is available at http://homeenergyscore.lbl.gov. In a major update to earlier work [4], this article introduces the initial version of the tool, describes how the conceptualization and analytical treatment of "asset" performance and scoring methodology have evolved, provides new information on validation of estimates against measured data, and presents new data on the status of deployment in the residential market.

The Scoring Tool is a key component of the DOE's residential labeling initiative within the Recovery Through Retrofit plan of the American Recovery and Reinvestment Act of 2009. The Home Energy Score Program (http://www.homeenergyscore.gov)

* Corresponding author. Tel.: +1 5104866784.
E-mail addresses: EMills@lbl.gov (E. Mills), NJbourassa@lbl.gov (N.J. Bourassa), LIRainer@lbl.gov (L.I. Rainer), GKHoman@lbl.gov (G. Homan), Noel.Merket@nrel.gov (N. Merket), dparker@fsec.ucf.edu (D. Parker), Glenn_Dickey@sra.com (G. Dickey), Joan.Glickman@ee.doe.gov (J. Glickman).

http://dx.doi.org/10.1016/j.enbuild.2014.05.044
0378-7788/© 2014 Elsevier B.V. All rights reserved.

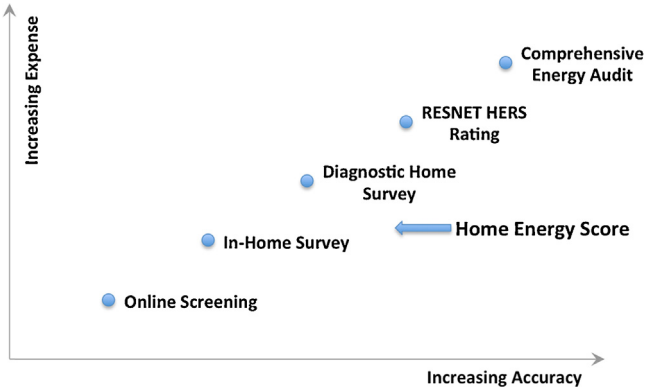


Fig. 1. The Home Energy Score vs. Home Energy Rating System (HERS) granularity.

provides the first nationally applicable asset rating method that allows all localities to voluntarily participate in a simplified and standardized energy assessment process.

The Home Energy Score has been designed to support and complement the marketplace of home energy analysis tools and services by providing a low-cost opportunity assessment of a home's fixed energy systems and providing home owners or authorized stakeholders with feedback that can help set priorities for more detailed attention from certified home performance diagnostics and weatherization professionals.

Consumers are accustomed to energy efficiency ratings for a wide variety of products, from refrigerators (EnergyGuide or Energy Star ratings) to vehicles (EPA miles per gallon ratings), but determining such a metric for homes is a far more complex proposition. Early in the project, a detailed review of existing home rating approaches was conducted and consumer focus groups were convened to test a variety of label concepts [5]. This background work created a basis for designing visual presentations comprehensible to consumers and support decision-making and implementation of energy-efficiency upgrades. This was followed up by an evaluation of homeowner assessments of pilot versions of the Home Energy Score rating and label [6].

In the United States home energy audit marketplace, the Residential Energy Services Network, (RESNET, www.resnet.us) and the Building Performance Institute (BPI, www.bpi.org) currently certify home audit professionals. While both organizations provide the same fundamental building science training, RESNET principally uses the Home Energy Rating System (HERS) standard [7] for rating home performance and has historically focused on newer homes built after 2004. In March of 2012, RESNET amended its standards in order to better address existing homes. BPI on the other hand provides a variety of professional certifications that target the energy performance improvement of both older and recently built homes.

Fig. 1 depicts how the Home Energy Score is targeted with respect to RESNET's characterization of home rating assessment methods [8]. The intention is to help service providers establish the potential energy savings and demonstrate to the homeowner the value of pursuing a more comprehensive audit that produces a formal retrofit work scope proposal. The cost of existing audits was identified as a barrier for many consumers, and the project sought to bridge this gap by developing a more streamlined assessment technique. Auditors surveyed as part of the DOE's 2011 Pilot Test of the Home Energy Score program reported that in a typical home an experienced assessor could complete a Scoring Tool analysis in under an hour. Comprehensive audits, which produce an upgrade work scope and that require detailed diagnostic testing, can take several times that long, at correspondingly higher cost.

In keeping with the goal of supporting the existing retrofit software market, we developed Application Programming Interface (API) web services within the Scoring Tool to enable DOE-approved third-party energy software developers to embed the nationally standardized Home Energy Score methodology into their products and business processes. For documentation, see https://developers.buildingsapi.lbl.gov/.

2. Methodology

2.1. Asset rating

In the strictest sense, an asset rating seeks to compare homes based on differences in their fixed characteristics, while holding occupant-determined factors and behaviors constant. An asset rating also excludes user-determined factors. Thus, the efficiency of a furnace would be regarded as an asset attribute while the operation of the thermostat controlling that furnace would be deemed a behavioral (non-asset) attribute. Similarly, energy-using devices such as televisions tend to move with the occupants, rather than being a permanent part of a home. There is some subjectivity in determining which energy-using components of a home are "assets". For the purposes of the Scoring Tool, space conditioning and water-heating systems (and the associated building envelope components) are considered asset components, while non-hardwired appliances, lighting, and other equipment are not.

However, a process of determining the characteristics and utilization of non-asset features is required for the stipulation of many factors about the home within the Scoring Tool. These include appliance power, saturation and use, lighting power and use, and the exclusion of non-standard features such as pools, workshops, and other rare miscellaneous loads. The Scoring Tool thus has limited application for informing home occupants on how to optimally operate their home, or for identifying retrofit opportunities for non-asset components. Asset ratings thus should not be expected to match individual utility bills. For these needs, the home must be modeled using full-fledged operational assessment tools such as the Home Energy Saver.

To ensure that assessors proactively define every asset characteristic, no input values are defaulted, and all input questions must be answered. For those systems not considered fixed assets (e.g., type of lighting and hours of use), values are not adjustable by the user and are set to be consistent with the defaults according to the Home Energy Saver methodology. For home characteristics that are not considered fixed assets and not individually entered into the Scoring Tool, key standardized default assumptions and algorithms largely match those of the Home Energy Saver Consumer and Pro tools, which are based on the best-available data and methodologies for modeling the energy use, costs, and greenhouse-gas emissions of homes in the US building stock [9–12]. For the latest engineering methods and a full list of sources, see http://hes-documentation.lbl.gov/.

2.2. Modeling considerations

2.2.1. Occupancy

The number of occupants is one of many influential drivers of energy use in the model, although not the most dominant. In the model occupancy affects hot water fixture draw and clothes washer and dishwasher cycles. Other miscellaneous loads and lighting are driven by floor area. To best put this in perspective, less than one-third of the total energy consumption is due to the hot water and miscellaneous end uses (including lighting). As implied by the formulas below, occupancy-sensitive loads increase roughly in proportion to 1.1–1.2 times number of occupants, with the

strength of the effect declining as number of occupants increases. Thus, for example, doubling the number of occupants (with otherwise identical relevant end-use devices) would correspond to an approximately 10% increase in whole-building energy use (30% of energy × 30% increase in demand). HVAC energy use represents a greater share of whole-building energy use than these occupant-driven loads, and thus a doubling in overall efficiency (equipment + envelope) would correspond to an even greater effect in final energy use than would a doubling in number of bedrooms/occupants.

While in its pure definitional form, an asset rating excludes the effects of occupancy and energy-using behavior, domestic hot water in particular cannot be meaningfully modeled without considering the number of occupants in a home. In particular, holding the number of occupants constant results in an insensitivity of hot water energy use across a wide range of conditions, leading to over-predictions for homes with low occupancy (but mitigated by the fact that a default of, say, three people can only overestimate the actual conditions by two people) and significant under-predictions for homes with high occupancy.

For this reason, we take the number of bedrooms (an "asset" characteristic) as a proxy of occupancy, using the Building America calculation method [13,14]. Since the HVAC model inputs require an integer and the formula produces a fractional result, we added a rounding function to the nearest integer. The implemented calculation and results relationship is the following:

$$\text{Occupants} = \text{ROUND}(0.59 \times \text{Nbr} + 0.87)$$
$$\text{Nbr} = \text{Number of bedrooms}$$

A secondary benefit of the bedrooms/occupancy calculation is a better scaling of the internal gains (which, in turn, affect heating and cooling energy use). Testing of these refinements in the model (in comparison to measured energy use for large numbers of homes) showed much better predictions of total home energy use than was the case with fixed occupancy and no dependence of MELs or lighting on floor area. Occupants/Nbr derived from RECS 2009 [9].

2.2.2. Space conditioning

Heating and cooling energy use is modeled using the DOE2.1E model. The current methodology is applicable to single-family homes and townhomes in the continental US and Hawaii. TMY3 (Typical Meteorological Year) weather data files for approximately 1000 US locations are used to simulate weather for a given building for the purpose of estimating heating and cooling energy use.

In keeping with the requirement to assess the asset rather than house-specific occupant behavior, the thermostat set point

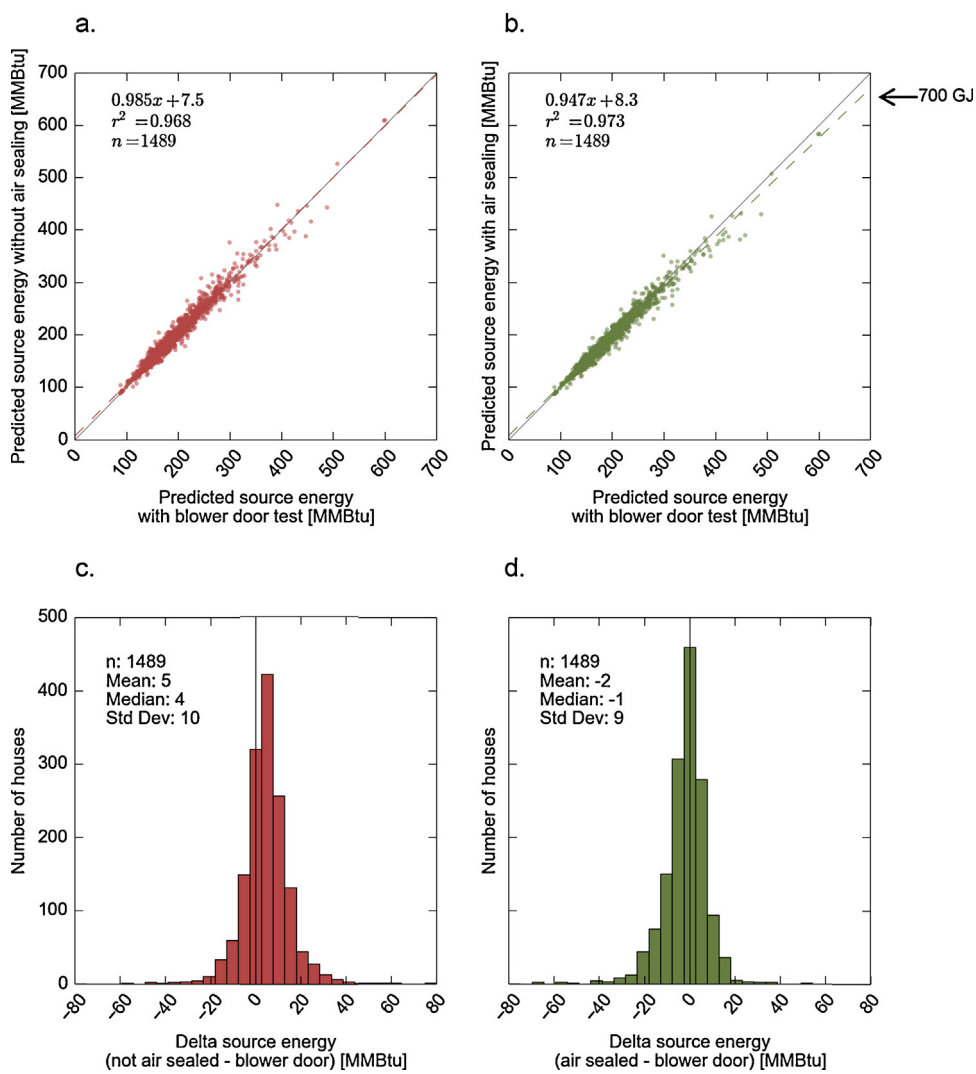


Fig. 2. (a–d) Predicted energy use with Home Energy Scoring Tool air leakage sub-model estimates versus in-field blower door measurements (with and without air sealing).

is scheduled 24.4 °C (76 °F) (night)/23.3 °C (74 °F) (day) in cooling mode, 18.3 °C (65 °F)/20.0 °C (68 °F) in heating mode, with a basement set point offsets upward for cooling and downward for heating, based on national survey data and other analyses [15]. While an operational assessment requires set point inputs that match actual use for each individual home, an asset rating requires a standardized thermostat setting so that the performance of the subject home can be compared to that of others, controlling for the otherwise confounding effects of individual behavior.

A key potential tradeoff involved in designing a data-collection methodology (audit) that can be conducted in roughly an hour is the lack of time for conducting air-leakage testing with a blower door. While the Scoring Tool allows the entry of measured air-leakage, it is not required. If air-leakage is not entered, the model estimates air leakage based on an extensive database of leakage measurements and associated building characteristics maintained at Lawrence Berkeley National Laboratory. Predicted energy use using actual and predicted air-leakage rates showed excellent agreement in unsealed homes (Fig. 2).

2.2.3. Hot water demand

The number of bedrooms directly affects the amount of calculated domestic hot water consumption for the household, including regular fixtures, dishwasher and clothes washer hot water use. The method [16] estimates total daily hot water use as a function of fixture use where skin sensitivity makes the consumption temperature-delivery dependent versus that for machines that are not:

$$\text{Total hot water use} = \text{Fixture liters per day} + \text{CWlpd} + \text{DWlpd}$$

with[1]

$$\text{Fixture liters per day} = F_{\text{mix}} \times 3.785 \times (30 + 10.0 \times \text{Nbr})$$

where F_{mix} = the fraction of fixture water consumption that is hot.

F_{mix} is determined by the target temperature, assumed to be 40.6 °C (105 °F) at point of end-use (T_{use}), the hot water supply temperature (T_{set}), and the inlet mains water temperature (T_{mains}).

Estimates of clothes washer and dishwasher hot water use are also taken from [16], where the actual hot water use is derived from the DOE energy guide label. We update that value to be consistent with the more recent RECS 2009 household survey data, based on occupancy to determine cycles per year for clothes washers and dishwashers.

$$\text{Clothes washer cycles per year (CWcpy)} = 164 + 45.6 \times \text{Number of bedrooms}$$

Given the water factor and estimated hot water use in [16], one can show that about 38% of the estimated water use (the Water Factor), is hot. However, another report [17] showed about 13% of washing machine water was hot in actual metering of 115 laundry systems. Other studies (detailed in [17]) showed about 18%, but nothing close to 38%. Given that, we make a simple adjustment that the estimated hot water use from the DOE procedure is reduced by 50% (0.5) to match what is seen in the field.

Again, from [16] Clothes washer hot water use per cycle:

$$\text{Clothes washer liters per cycle (CWlpc)} = 36.4 \times 0.5 = 18.2$$

$$\text{Clothes washer hot water liters per day (CWlpd)} = \text{CWlpc} \times \frac{\text{CWcpy}}{365}$$

For dishwashing the stock average dishwasher has an energy factor (EF) of 0.46.

$$\text{Dishwasher cycles per year (DWcpy)} = 88.4 + 34.9 \times \text{Number of bedrooms}$$

$$\text{Dishwasher liters per cycle (DWlpc)} = 17.56 \times \frac{1}{0.46} - 7.30 = 30.87$$

$$\text{Dishwasher hot water liters per day (DWlpd)} = \text{DWlpc} \times \frac{\text{DWcpy}}{365}$$

2.2.4. Miscellaneous loads and lighting

In addition, we make Miscellaneous Electric Loads (MELS) and lighting electricity use proportional to floor area or numbers of bedrooms [16].

$$\text{Residual miscellaneous electricity use (kWh/year)} = 9.79 \times \text{Conditioned floor area (m}^2\text{)}$$

and

$$\text{TV electricity use (kWh/year)} = -3 \times (\text{Number bedrooms})^2 + 89 \times (\text{Number of bedrooms}) + 390$$

Scaling televisions by number of bedrooms captures the effects of occupancy more effectively than would simply linking television use to house size. The remaining plug loads are scaled by floor area.

We employ the following algorithms to estimate lighting use, based on [16]:

$$\text{Interior lighting electricity use (kWh/year)} = 455 + 8.6 \times \text{Conditioned floor area (m}^2\text{)}$$

$$\text{Exterior lighting electricity use (kWh/year)} = 50 + 0.538 \times \text{Conditioned floor area (m}^2\text{)}$$

Lastly, in keeping with a standardized asset-based framework, the predicted energy cost savings assume state-average energy prices and include improvements to home envelope and major equipment, but do not include upgrades of non-asset lighting and appliances or usage changes. As a result, predicted energy costs for a given home can be expected to differ from actual utility bills to a greater degree than in fully-specified operational assessments. The extent of these variations will depend on additional factors such as local economic conditions, how the occupant maintains their home, appliance ownership and amount of use, actual number of occupants, and year-to-year weather variations.

2.3. Required inputs

The Scoring Tool has five screens of required user inputs used to describe the home construction and equipment (Fig. 3). The total number of required inputs is typically less than 50 if the home has the same window and wall types on each building side. Unlike the Home Energy Saver website, the Scoring Tool does not pre-populate inputs with defaults; all inputs must be provided and authorized by the user. A concise list of the inputs is provided in Table 1.

[1] Showers: 14.0 + 4.67(bedrooms); Baths: 3.5 + 1.17(bedrooms); Other faucets: 12.5 + 4.16(bedrooms). Aggregate total = 30.0 + 10(Bedrooms) × F_{mix}.

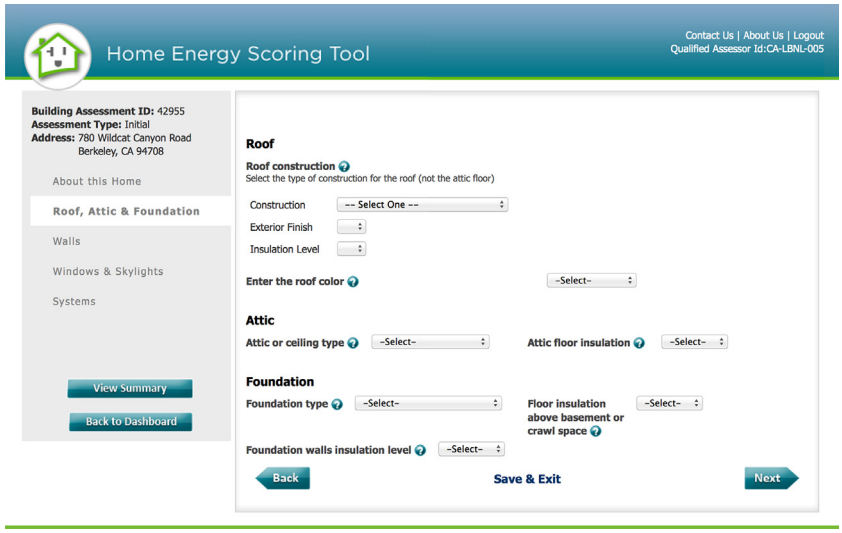


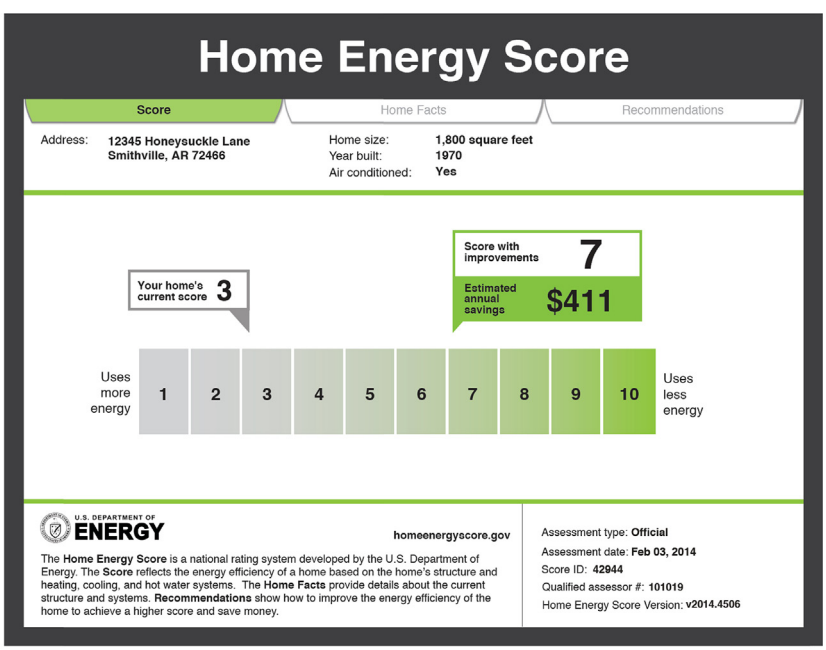
Fig. 3. Input page example.

Extensive model input sensitivity analyses, balanced with considerations of audit time implications, were conducted with the goal of determining which inputs to require [18]. The study conducted an analysis of 88 measures and determined that air leakage, duct leakage, ceiling height, and building shape (in order of results sensitivity) were important to include in the final Scoring Tool. The first three have been implemented in the national release version, while building shape may be considered in future versions.

2.4. Scoring

Many factors and available data sources were considered in an effort to develop a scoring system that could fairly compare the energy performance of existing homes. The objective was to provide a simple system that helps consumers understand how homes compare in energy performance anywhere in the country, accounting as much as possible for regional construction differences, dominant energy sources, and differing climate. The resulting methodology is applicable to single-family and townhouse residential dwellings.

The Scoring Tool rates a home on a 10-point scale, where a 10 corresponds to highest efficiency (lowest energy use) (Fig. 4). Each point on the scale corresponds to a specific band of source energy use [19]. National average source energy factors were selected instead of site energy, since a key requirement of the program is to adequately characterize the wider energy system impacts and different mixes of energy types. Given that heating and cooling loads vary considerably across the U.S., the system uses a suite of



Note: The label includes additional pages summarizing the home inputs, measures recommended, and tips for non-asset measures.

Fig. 4. Home Energy Score label – front page.

Table 1
List of required inputs.

About this home	• Assessment date • Year built • Number of bedrooms • Stories above ground • Interior floor-to-ceiling height • Conditioned floor area • Direction faced by front of house • Measured or estimated air leakage rate • Whether home was professional air-sealed
Roof, attic and foundation	• Roof construction • Roof color or exterior roof absorptance • Attic or ceiling type • Insulation level of the attic floor • Foundation type • Foundation insulation level • Insulation level of the floor above the basement or crawlspace
Walls	• Building type; townhouse or otherwise • Building position; if townhouse • Walls construction same on all sides ○ Front; back; right; left ■ Materials ■ Insulation levels
Windows and skylights	• Does house have skylights • Skylight size • Skylight type ○ Glazings, frames, fill ○ *U*-Factor ○ Solar heat gain coefficient • Window areas • Window types are same on all sides ○ Front; Back; Right; Left ■Glazings, frames, fill ■ *U*-Factor ■ Solar heat gain coefficient
Systems	• Type of heating system • Heating system efficiency • Year heating system installed • Type of cooling system • Cooling system efficiency • Year cooling system installed • Duct location; up to three • Percentage of total ducts in each location • Duct insulation • Duct sealing • Water heater type • Year water heater installed • Water heater energy factor

customized source energy scoring bins and bin ranges vary according to region, with the lowest bin always defined as the 80th percentile of the building stock for that area (per the 2009 Residential Energy Consumption Survey) and the highest defined as the 12th percentile, with intervening bins defined by equal-sized bins (ranging from 5 to 30 GJ/bin (5–28 MMBtu/bin), depending on location).

A score is assigned for the base home, and another for the home as evaluated when applicable energy upgrades are applied and the simulation re-run. To most fully reflect the value of asset-based upgrades, scores are computed based on the energy use associated with those features (essentially heating, cooling, and water-heating).

3. Market deployment

3.1. Pilot test version

A pilot version of the Scoring Tool was tested in nine regions across the country during the spring/summer of 2011, in which approximately 1000 homes were rated. Through these diverse pilot programs, the DOE and the pilot test partners were able to explore a wide range of issues associated with the modeling and scoring methods. It was confirmed that assessors could collect as well as enter the required data into the tool in less than an hour. In addition to gathering feedback from auditors, 151 homeowners were also surveyed to gain understanding of their perception of the home energy scoring process [7]. Of these homeowners, 83% was "satisfied" or "very satisfied" with the overall home scoring experience, and a similar number reported that the reports would help them prioritize their potential upgrades. In addition, 88% found the scoring scale easy to understand, and a similar number reported being convinced by the process to make energy-saving improvements.

For the development of a test version of the Scoring Tool, the team used the Home Energy Saver website which extensively employs EIA Residential Energy Consumption Survey (RECS) micro data for model input defaults [10,20]. Within the Home Energy Saver websites, the RECS micro data are categorized into 19 regions (RECS Zones),[2] originally developed by LBNL [21–23].

Drawing from the RECS data, different source energy ranges for each RECS Zone were established. For example, the energy range for the 10-point scale in Minneapolis is greater than the range in San Diego – given that San Diego is a much milder climate. By calibrating the range of potential energy results in each zone, the 10-point score could be applied in a consistent manner nationally.

Within each of the 19 data sets, the top and bottom 2 percentiles of high-energy and low-energy outlier points were excluded and the remaining data were sorted by energy use. The RECS energy consumption data were not normalized by home size or weather location and the absolute energy consumption values were maintained throughout. Each data set was then divided into 10 equally sized energy bins and the energy value at the top of each bin was extracted, producing a set of 10 scoring thresholds from low to high energy use. The resulting scores reflected acceptably normal distributions (Fig. 5).

As an adjustment method for the operational energy use component that is implicitly embedded in RECS, Home Energy Saver models constrained to asset-based assumptions were run in each zone. The results were used to adjust the scoring bin range and bin sizes with care taken to assure an acceptable range of score mobility within each bin set. Key observations included the ability of energy efficiency improvements to affect score improvements ("score mobility") and maintaining acceptable capacity at the high-energy efficiency range to accommodate an improving building stock over time.

3.2. Upgrade recommendations

In keeping with the asset-based methodology, a consistent set of upgrade recommendation opportunities are analyzed for each scored home (variations of which are ultimately recommended as a function of home characteristics, cost-effectiveness, etc.). Upgrades calculated in the Scoring Tool include improvements to the building envelope and major equipment (the "assets"), but not to lighting and appliances or any occupant usage changes. The Scoring Tool applies a fixed, national average standardized retrofit cost derived from the NREL National Residential Efficiency Measures Database (http://www.nrel.gov/ap/retrofits). The upgrade recommendations are categorized as either "Repair Now", items such as envelope and duct improvements, or "Replace Later", items for upgrades that make economic sense only at the time of replacement

[2] https://sites.google.com/a/lbl.gov/hes-public/calculation-methodology/default-energy-consumption-and-house-configuration/average-energy-bills-for-existing-houses.

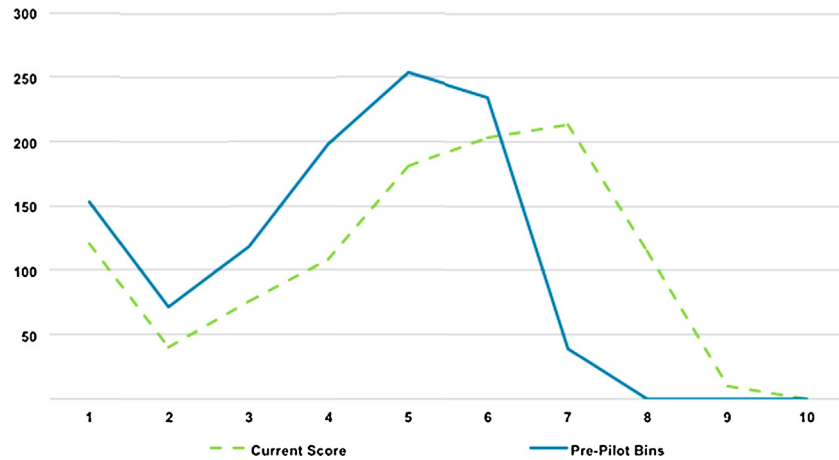


Fig. 5. Pilot test home scores.

or repair. Savings are calculated as the difference between the existing home's energy consumption and that with the given upgrades applied. Where available, upgrade efficiency levels corresponding to Energy Star are assumed.

The label displays the existing home's score, alongside the score and savings the home would obtain by implementing a package of measures that pay for themselves within 10 years. In the supporting documentation provided with the label, all of the "Repair Now" recommendations are listed with their estimated annual energy savings in dollars per year and the list is limited to items achieving a simple payback of less than 10 years. All of the "Replace Later" recommendations are listed with their estimated annual energy savings in dollars per year, with all items included that have annual cost savings of greater than $20. Since simple payback is calculated using a national average measure cost and state-average energy prices, these recommendations are only intended to provide a list of likely opportunities to assist the homeowner in identifying areas that can benefit from a more comprehensive audit and retrofit recommendation report from a local home energy audit professional.

The following categories of specific upgrades are currently provided by the Scoring Tool:

Type 1 – Improvements recommended now – These upgrades can help save energy right away. The incremental cost used for the cost–benefit analysis is the full cost of installation.

- Attic insulation
- Basement/crawlspace wall insulation
- Basement/crawlspace floor insulation
- Building envelope air-sealing
- Exterior wall insulation
- Duct sealing
- Duct insulation

Type 2 – Recommendations for when you need to replace equipment –These recommendations can help save energy when its time to replace or upgrade. The incremental cost used for the cost–benefit analysis is the cost differential between equipment complying with current standards and cost of the upgrade (Energy Star, where applicable).

- Central or room air conditioner
- Boiler or furnace or heat pump
- Roof – reflectance
- Roof – insulated sheathing
- Skylights
- Siding – insulated sheathing
- Water heater
- Windows

It is important to note that the sum of the savings from the individual measures in the recommendations report may not equal the total savings for the package of selected upgrades (the number shown on the front page label). The difference is due to interactive effects of individual energy improvements. When improvements reduce energy consumption within the same end-use (e.g., a window upgrade plus an air conditioner upgrade), the resulting dollar savings is less than the sum of the savings shown for the individual improvements.

3.3. Evolution of versions in use

Pilot testing results suggested a need to reconsider bin values in some climates, especially in more energy intensive heating climates. Immediately, at the beginning of the pilot test the pre-pilot bins required adjustments for energy intensive regions.

In parallel with the pilot testing, an in-depth analysis and update of the modeling defaults was conducted. A significant number of model defaults were updated and the changes are documented on the public Home Energy Saver website.[3]

In response to scoring bin adjustments that were identified during the pilot projects and from general public stakeholder input, we converted to a more climate-responsive scoring method (described in the previous section) by creating individual scoring bins sets for each of the TMY3 weather files that the Scoring Tool uses for the source energy use calculation. This enables the tool to issue a Home Energy Score on a much finer climate resolution than the 19 RECS Zone set used in the pilot test version. Using custom Scoring Tool batch API scripts, thousands of prototypical home models were run through 245 USA weather climate locations (at the time, TMY2 weather files were in use; currently TMY3). Once again, as was done for the pilot test version, care was taken to design bin sets that assure a fair range of scoring mobility in each weather region.

The Home Energy Scoring Tool was initially deployed in 2012. Updates of the Scoring Tool energy calculation methods, reference data and the included building components are released annually as new assessment methods are vetted within the building science community and modeling techniques improved. The necessary

[3] Release History section at https://sites.google.com/a/lbl.gov/hes-public/home-energy-scoring-tool/release-history.

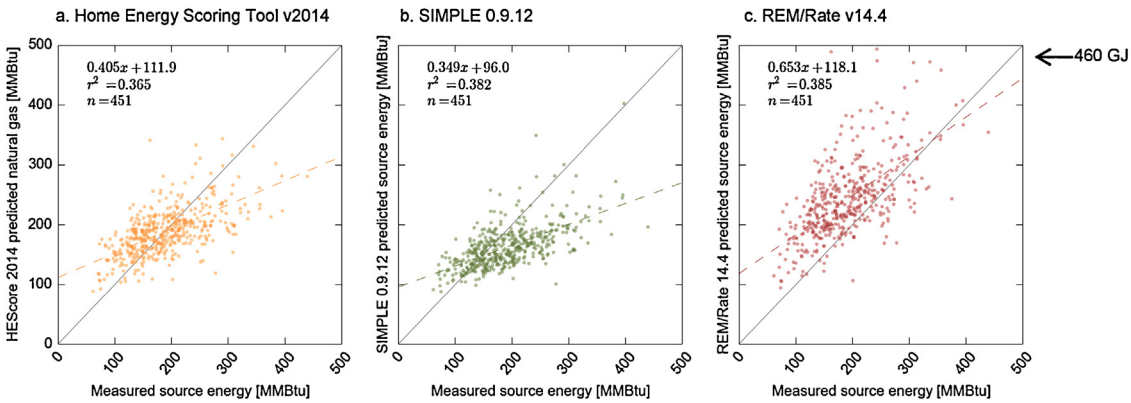


Fig. 6. (a–c) Comparison of the Home Energy Scoring Tool, SIMPLE, and REM/Rate energy estimates.

Table 2
Statistical summary of validation exercise results (N = 451 homes).

	HEScore v2014	Simple v0.9.12	REM/Rate v14.4
Mean measured energy use (MBTU)	200 GJ (190 MMBtu)	200 GJ (190 MMBtu)	200 GJ (190 MMBtu)
Mean predicted energy use (MBTU)	199 GJ (189 MMBtu)	172 GJ (163 MMBtu)	256 GJ (243 MMBtu)
Mean error (%)	−1	−14	28
Percent within 25% of mean (%)	82	67	49
Percent within 50% of mean (%)	97	99	81

Scoring Tool system infrastructure has been put in place to facilitate a recalculation of prior scores when needed. The latest version was released in January 2014.

4. Accuracy assessment

The accuracy of operational energy use estimates by the Home Energy Saver simulation system underlying The Scoring Tool has been established, with predictions within 1% of actual bills *averaged* across a large cohort of homes located in a range of weather zones [24].

Defining the expectations for accuracy of an asset-based modeling protocol is more nuanced, given that behavioral factors are normatively held constant and standardized defaults are applied to many loads, and unusual loads that would confound the scoring process in a real home (well pumps, workshops, pools, etc.) are assumed not to be present. Thus, significant differences can be expected between measured and predicted energy use for a *given* home, especially if that home is in any way non-average. These caveats notwithstanding, an asset-based tool would ideally produce estimates near the *average* bill for a large, diversified set of actual homes.

This is indeed the case for Home Energy Score (Fig. 6), which achieved excellent agreement with actual consumption among accuracy testing alongside two other popular asset analysis methods: SIMPLE (the basis of some other tools) and REM/Rate. The analysis is based on the audit and billing data of 451 occupied homes in Oregon, Wisconsin, and Minnesota. Field data were translated into HES inputs from REM/Rate inputs in NREL's Building America Field Data Repository, an updated version of which is used here [25].

Upon implementing improvements to the calculation methodology,[4] as embodied in the current (2014) version of the Scoring Tool, accuracy was found to be approximately −1% of mean actual bills, with SIMPLE under-predicting by 14% and REM/Rate over-predicting by 28% (Fig. 7). These are *average* results over the entire test set; the variations can be seen in Fig. 6 and Table 2.

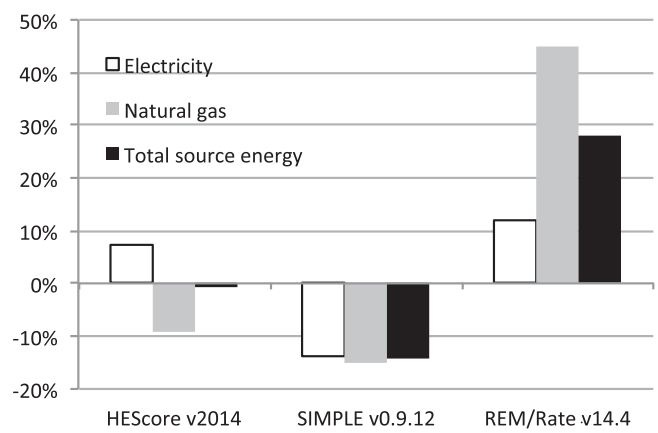


Fig. 7. Mean prediction errors: 451 homes.

The Scoring Tool's results are the most symmetrically distributed (see Fig. 6). Note that the share of homes within a certain error band in Table 2 arithmetically represents *absolute* values and thus obscures the downward skew (under-prediction) exhibited by SIMPLE and the upward skew (over-prediction) exhibited by REM/Rate.

5. National program deployment

In order to use the Scoring Tool and the Home Energy Score program, the user must become a DOE Qualified Assessor (QA) by meeting the following requirements:

[4] Examples include improved modeling of duct-loss heat regain through flooring systems improved heat pump and air conditioner models, ability to define three distinct duct runs and their locations, improved air-leakage model, an improved hot-water draw model, switch from TMY2 to TMY3 weather data, updated upgrade cost data, and additional technologies (e.g., geothermal heat pumps, heat-pump water heaters, and evaporative cooling). See on-line documentation for full details.

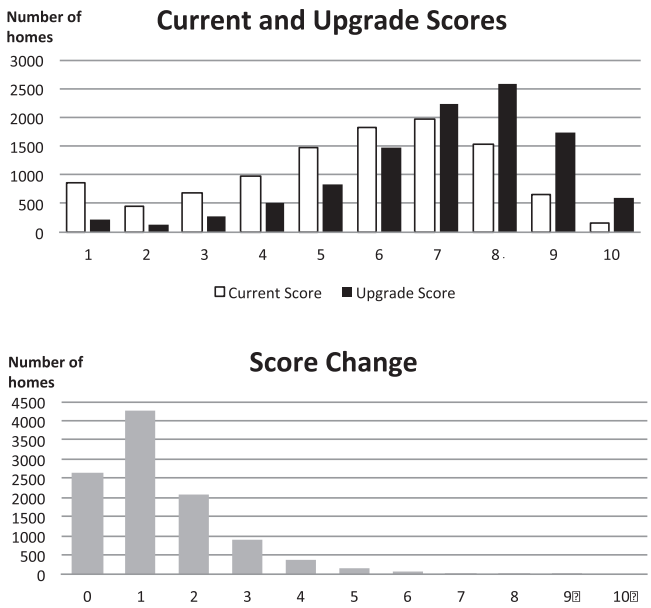


Fig. 8. Distribution of base and upgrade scores for 10,601 homes.

- Be working directly with a Home Energy Score Local Partner,[5]
- Be certified by the Building Performance Institute (BPI) or by a Residential Energy Services Network (RESNET) Provider, and
- Complete and receive a passing grade on the DOE's Home Energy Score online training module and test.

This approach was deemed important as a means to help distribute the front-line administrative functions to partners that are well established in specific localities and market segments. The Partners are then also able to play a constructive role in managing providers and ensuring quality of the services delivered. Homes began being scored in July of 2012. As of April 2014, 195 assessors had been trained and qualified to use the tool, and have collectively scored 10,610 homes (Fig. 8).

The Program also contains an element that supports third-party software developers. The Scoring Tool backend server calculations are implemented as an API web service [26]. Eventually, as the program grows and delivers scores in a majority of U.S. regions, the valuable data can be combined with existing and future RECS data to help improve the energy benchmarking capabilities of the Scoring Tool. Additionally, the growing repository of data will help the building science community better understand the relative energy efficiency of the existing residential building stock, helping target effective energy efficiency programs and market support strategies.

6. Conclusions

The Home Energy Score provides a simple, transparent and low-cost method for communicating how much energy a home is likely to use under standardized conditions. It is one strategy to help consumers understand that energy efficiency has value. The Home Energy Scoring Tool underpins the DOE's Home Energy Score Program for residential building energy labeling, analogous to the "miles-per-gallon" ratings associated with vehicles.

In-depth validation work found the tool to predict source energy use, *on average*, within 1% of mean values across large numbers of well-characterized occupied homes. Although the Scoring Tool has been in the market for less than two years, the program has garnered a substantial user base, with 10,600 homes scored by 23 partner organizations as of April 2014.

DOE continues to evaluate and enhance the tool; improve program offerings; and, assess how effectively the score motivates homeowners, sellers, and buyers to invest in energy improvements and place a premium on more efficient homes. Meanwhile, DOE is increasing the number of partners throughout the country, welcoming all local governments, utilities, and non-profit organizations that have existing energy efficiency programs.

[5] Local partner details located at www.homeenergyscore.gov.

Acknowledgments

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy and the Building Technologies Program, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. The Home Energy Saver and Home Energy Scoring Tool core team also includes software engineers from Bighead Technologies. Helpful comments were provided by Iain Walker and two anonymous reviewers.

References

[1] IPCC Synthesis Report, Climate Change 2007, Cambridge University Press, Cambridge, UK/New York, 2007.
[2] USDOE, 2011 Buildings Energy Data Book, U.S. DOE, Office of Energy Efficiency and Renewable Energy, 2014, http://buildingsdatabook.eren.doe.gov/DataBooks.aspx
[3] E. Mills, et al., Home Energy Saver: Documentation of Calculation Methodology, Input Data, and Infrastructure. LBNl-51938, 2007, Updates available at https://sites.google.com/a/lbl.gov/hes-public/
[4] N.J. Bourassa, L.I. Rainer, E. Mills, J. Glickman, The home energy scoring tool: a simplified asset rating for single family homes, in: Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, Washington, DC, 2012.
[5] USDOE, Motivating Home Energy Improvements: Focus Groups for the U.S. Department of Energy, U.S. Department of Energy, Building Technologies Office, 2010.
[6] C. McDermitt, 2011 Home Energy Score Pilot Program: Homeowner Understanding and Interest, U.S. Department of Energy, Building Technologies Office, Washington, DC, 2012.
[7] RESNET, Mortgage Industry National Home Energy Rating Standards, 2006 (March, 2012 Amendment).
[8] P. Fairey, Time of sale energy labeling of homes: a concept, Home Energy Magazine (2010), July.
[9] USDOE 2009, Residential Energy Consumption Survey (RECS): Public-Use Microdata Files, Energy Information Administration (EIA), U.S. DOE, Washington, DC, 2005, http://www.eia.gov/consumption/residential/
[10] M. Sherman, N. Matson, Residential ventilation and energy characteristics, ASHRAE Transactions 103 (1) (1997) 717–730 (American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA).
[11] M.C. Sanchez, J.G. Koomey, M. Moezzi, A.K. Meier, W. Huber, Miscellaneous Electricity Use in the U.S. Residential Sector, Lawrence Berkeley National Laboratory, Berkeley, CA, 1998, LBNL-40295, April.
[12] J.D. Lutz, X. Liu, J.E. McMahon, C. Dunham, L.J. Shown, Q.T. McGrue, Modeling Patterns of Hot Water Use in Households, Lawrence Berkeley National Laboratory, Berkeley, CA, 1996, LBNL-37805, November.
[13] R. Hendron, C. Engebrecht, Building America House Simulation Protocols, National Renewable Energy Laboratory, 2010, NREL:TP-550-49426, DOE/GO-102010-3141.
[14] R. Hendron, C. Engebrecht, Building America Research Benchmark Definition: Updated December 2009, National Renewable Energy Laboratory, 2010, TP-550-47246.
[15] D. Parker, Determining Appropriate Heating and Cooling Thermostat Set Points for Building Energy Simulations for Residential Buildings in North America, Florida Solar Energy Center for Lawrence Berkeley National Laboratory, 2013.
[16] D. Parker, P. Fairey, R. Hendron, Updated Miscellaneous Electricity Loads and Appliance Energy Usage Profiles for use in Home Energy Ratings, Building America Benchmark Procedures and Related Calculations. Florida Solar Energy Center Report FSEC-CR-1837-10, Prepared for the U.S. Department of Energy, Building America Program, 2010, http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1837-10-R01.pdf
[17] D. Korn, S. Dimetrosky, Do the savings come out in the wash? A large scale study of in-situ residential laundry systems, in: Proceeding of 2010 ACEEE Summer Study on Energy Efficiency in Buildings, ACEEE, Washington, DC, 2010.
[18] ICF International, Task 1 – Sensitivity Analysis: Existing Home Asset Rating Sensitivity Analysis, Existing Software Tool Comparison, and Methodology for Estimating Home Characteristics. Report to the Department of Energy, 2010, November.

[19] US EPA, Portfolio Manager Technical Reference, U.S. Environmental Protection Agency, Washington, DC, 2013, July, http://www.energystar.gov/buildings/tools-and-resources/portfolio-manager-technical-reference-source-energy
[20] USDOE, 2009 Residential Energy Consumption Survey (RECS): Public-Use Microdata Files, Energy Information Administration, U.S. Department of Energy, Washington, DC, 2012, http://www.eia.gov/consumption/residential/
[21] R.L. Ritschard, J.W. Hanford, A.O. Sezgen, Single-Family Heating and Cooling Requirements: Assumptions, Methods, and Summary Results, Lawrence Berkeley Laboratory, for the Gas Research Institute, 1992, LBL-30377, GRI-91/0236, March.
[22] Y.J. Huang, R. Ritschard, J. Bull, S. Byrne, I. Turiel, D. Wilson, C. Hsui, D. Foley, Methodology and Assumptions for Evaluating Heating and Cooling Energy Requirements in New Single-Family Residential Buildings. Technical Support Document for the PEAR Microcomputer Program, Lawrence Berkeley Laboratory, 1987, LBL-19128, January.
[23] J.S. Apte, Residential Windows, Greenhouse Gas Emissions and the Potential of Emerging Window Technologies (Baccalaureate thesis), Brown University, 2004, May.
[24] D. Parker, L. Rainer, N. Bourassa, E. Mills, Validation of the home energy saver calculation methodology, in: Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings, ACEEE, Washington, DC, 2012.
[25] D. Roberts, N. Merket, B. Polly, M. Heaney, S. Casey, J. Robertson, Assessment of the U.S. Department of Energy's Home Energy Scoring Tool. National Renewable Energy Laboratory Report, 2012.
[26] E. Mills, P. Mathew, Web services that foster innovation in buildings energy analysis tools, in: Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, Washington, DC, 2012.