August 2004 • NREL/CP-550-35917

Conference Paper

Development of an Energy Savings Benchmark for All Residential End-Uses

Preprint

R. Hendron, R. Anderson, C. Christensen, and M. Eastment
National Renewable Energy Laboratory

P. Reeves
Partnership for Resource Conservation

To be presented at the SIMBUILD2004 Conference
Boulder, Colorado
August 4–6, 2004

National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
303-275-3000 • www.nrel.gov

Operated for the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337

NOTICE

The submitted manuscript has been offered by an employee of the Midwest Research Institute (MRI), a contractor of the US Government under Contract No. DE-AC36-99GO10337. Accordingly, the US Government and MRI retain a nonexclusive royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for US Government purposes.

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

DEVELOPMENT OF AN ENERGY SAVINGS BENCHMARK FOR ALL RESIDENTIAL END-USES

Robert Hendron[1], Ren Anderson[1], Craig Christensen[1], Mark Eastment[1], and Paul Reeves[2]
[1]National Renewable Energy Laboratory, Golden, CO
[2]Partnership for Resource Conservation, Boulder, CO

ABSTRACT

To track progress toward aggressive multi-year whole-house energy savings goals of 40-70% and onsite power production of up to 30%, the U.S. Department of Energy (DOE) Residential Buildings Program and the National Renewable Energy Laboratory (NREL) developed the Building America Research Benchmark in 2003. The Benchmark is generally consistent with mid-1990s standard practice, as reflected in the Home Energy Rating System (HERS) Technical Guidelines, with additional definitions that allow the analyst to evaluate all residential end-uses, an extension of the traditional HERS rating approach that focuses on space conditioning and hot water. A series of user profiles, intended to represent the behavior of a "standard" set of occupants, was created for use in conjunction with the Benchmark. Finally, a set of tools was developed by NREL and other Building America partners to help analysts compare whole-house energy use for a Prototype house to the Benchmark in a fair and consistent manner.

INTRODUCTION

The U.S. Department of Energy's (DOE's) Buildings Technology Program, including such initiatives as Building America and Zero Energy Homes, has recently entered a new phase of research that extends beyond a traditional emphasis on reducing space conditioning and hot water loads to include all residential energy uses. This extension reflects the significant progress that has been made in reducing space conditioning loads in new housing in most U.S. climates and the need to continue to reduce all end use loads as part of a comprehensive energy strategy.

The current multi-year objectives of the program target systems-based energy efficiency improvements capable of reducing whole-house energy consumption by 40-70%, while advanced site generation systems offset the remainder of the load to achieve zero net energy consumption on an annual basis by 2020. Because of this new emphasis on reducing whole-house energy and integrating onsite power systems, the Building America teams are now researching opportunities to improve energy efficiency for some of the more challenging end-uses, such as lighting (both fixed and occupant-provided), appliances (clothes washer, dishwasher, dryer, refrigerator, and range), and miscellaneous plug loads, which are all heavily dependent on occupant behavior and product choices. These end-uses have grown to be a much more significant fraction of total household energy use (Figure 1) as energy efficient homes have become more commonplace through programs such as Energy Star® and Building America.

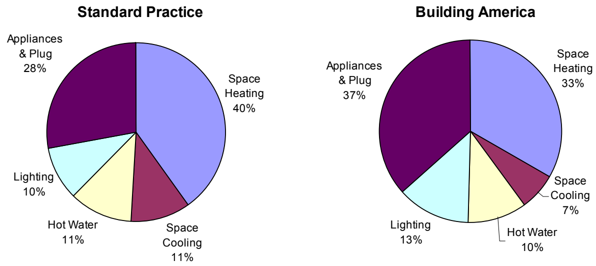


Figure 1. Contribution of lighting, appliances, and plug loads toward whole-house energy consumption for a Building America research house in Albuquerque compared to standard practice (BSC 2004).

BUILDING AMERICA RESEARCH BENCHMARK

The following sections summarize the definition of the Benchmark, developed by NREL for DOE to allow a consistent basis for tracking Building America's progress toward aggressive multi-year whole-house research goals. The Benchmark was created based on review of the available literature with the intent of representing standard occupant behavior and typical 1990s construction. A more comprehensive description of the Benchmark, along with definitions of other important Building America reference houses, can be found in the NREL technical report addressing systems-based performance analysis of residential buildings (Hendron 2004) and on the Building America web site (www.eere.energy.gov/buildings/building_america/ benchmark_def.html).

Building Envelope and Space Conditioning

The building envelope and space conditioning components for the Benchmark are by and large consistent with the HERS Reference Home (RESNET 1999). A few minor clarifications and additional details were added by NREL to ensure that credit was given for important energy saving measures frequently employed by Building America teams, and to make the Benchmark more realistic. The key differences are summarized in Table 1.

Table 1. Key differences between Benchmark and HERS Reference Home

Design Feature	HERS Reference Home	BA Research Benchmark
Attic venting	Same as proposed house	Always vented, unconditioned
Infiltration in conditioned basement	Same specific leakage area as above-grade floors	Specific leakage area adjusted based on exposed fraction of basement walls
Framing factors	Light frame construction	23% for walls, 13% for floors, 11% for ceilings
Dehumidification	Not addressed	No supplemental dehumidification
Duct losses	80% distribution efficiency in all cases	Distribution efficiency depends on prototype air handler location, climate, number of stories, floor area
Ventilation	Not addressed	Typical exhaust fan meeting ASHRAE 62.2 guidelines
Air handler	Not addressed	0.55 Watts/cfm

Domestic Hot Water

The basic properties of the Benchmark domestic hot water (DHW) system are the same as those for the HERS Reference Home. Storage and burner capacities for the DHW system are determined using the guidelines recommended by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) in the HVAC Applications Handbook (ASHRAE 1999), which are based on the minimum capacities permitted by the U.S. Department of Housing and Urban Development (HUD 1982).

Four major end-uses exist for domestic hot water: showers, sinks, dishwasher, and clothes washer. The average daily water consumption by end-use is shown in Table 2. The specified volume is the combined hot and cold water for showers and sinks, which allows hot water use to fluctuate depending on cold water (mains) temperature. Hot water usage for the clothes washer and dishwasher are derived from the EnergyGuide labels for the least efficient of several common models sampled by NREL. For showers and sinks, the water usage is based on the average of four domestic hot water studies (Christensen et al. 2000, Burch and Salasovich 2002, ASHRAE 1999, and CEC 2002).

Table 2. Domestic hot water consumption by end-use.

End-Use	End-Use Water Temperature	Water Usage
Clothes Washer	N/A	7.5 + 2.5 x N_{br} gal/day[1] (Hot Only)
Dish-washer	N/A	2.5 + 0.833 x N_{br} gal/day (Hot Only)
Shower and Bath	105°F	14 + 4.67 x N_{br} gal/day (Hot + Cold)
Sinks	105°F	10 + 3.33 x N_{br} gal/day (Hot + Cold)

The ASHRAE domestic hot water profile (Figure 2) represents typical, aggregated hot water consumption for clothes washers, dishwashers, sinks, and showers. This profile is normalized as a fraction of daily total hot water consumption, which is the form used in many hourly energy simulation tools such as DOE-2. NREL is in the process of investigating profiles for individual hot water end-uses, as well as common event schedules, which are important for quantifying energy savings for solar hot water systems. Usage profiles at this level of detail have not been studied extensively to date.

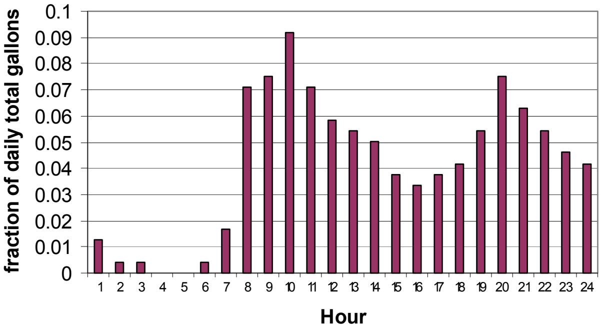


Figure 2. Hot water use profile (ASHRAE 1999).

---

[1] Where: N_{br} = number of bedrooms

The mains water temperature for a typical house varies significantly depending on location and time of year. Equation 1, which is based on Typical Meteorological Year (TMY2) data for the location of the Prototype, is used to determine daily mains water temperature for both the Benchmark and Prototype:

(1) $T_{mains} = (T_{amb,avg} + \text{offset}) + \text{ratio} \times (\Delta T_{amb,max} / 2) \times \sin(0.986 \times (\text{day\#} - 15 - \text{lag}) - 90)$

where: T_{mains} = mains (supply) temperature to domestic hot water tank (°F)

$T_{amb,avg}$ = annual average ambient air temperature (°F)

$\Delta T_{amb,max}$ = maximum difference between monthly average ambient temperatures (e.g., $T_{amb,avg,july} - T_{amb,avg,january}$) (°F)

0.986 = degrees/day (360/365)

day# = Julian day of the year (1-365)

offset = 6°F

ratio = $0.4 + 0.01 \times (T_{amb,avg} - 44)$

lag = $35 - 1.0 \times (T_{amb,avg} - 44)$ (°F)

This equation is based on analysis by Craig Christensen and Jay Burch of NREL using data for multiple locations compiled by Abrams and Shedd (1996), the Florida Solar Energy Center, Sandia National Laboratories, and others. When using this equation, a lower limit of 32ºF should be enforced for T_{mains} regardless of the local weather conditions. The offset, ratio and lag factors were determined by fitting a sinusoidal curve to the available data. The climate-specific ratio and lag factors reflect the practice of burying water pipes deeper in colder climates.

For models that use average monthly mains temperature, Equation 2 is used to calculate day#.

(2) day# = 30 x month# - 15

An example using Equation 2 to determine the monthly mains temperature profile for Chicago, Illinois, is shown in Figure 3. Average daily hot water usage (labeled DHW gal/day) was calculated using the equations in Table 2 based on cold water supplied at the mains temperature and hot water supplied at 120°F.

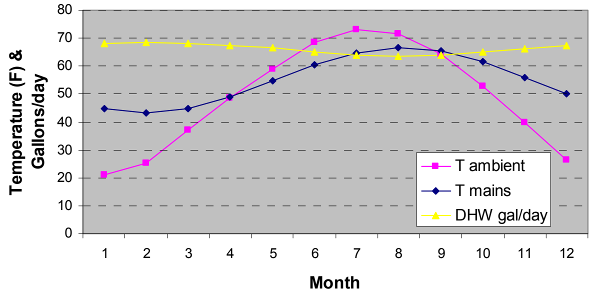


Figure 3. Mains temperature profile for Chicago

Lighting

The total annual lighting use for the Benchmark is determined using Equations 3-5. These equations are derived from data for both single-family and multi-family housing documented in a lighting study conducted by Navigant for DOE (Navigant 2002).

(3) Interior Lighting = (FFA * 0.8 + 455) kWh/yr

(4) Garage Lighting = 100 kWh/yr

(5) Exterior Lighting = 250 kWh/yr

Annual indoor lighting kWh is expressed as a linear function of finished house area relative to a constant base value, while garage and exterior lighting are constants. This equation is in the middle range of residential lighting energy use found in other lighting references, as shown in Figure 4, including Huang and Gu (2002), the 1993 Residential Energy Consumption Survey (RECS) (DOE 1996), a Florida Solar Energy Center study (Parker 1992), default lighting for Visual DOE software (Eley 2002), a lighting study conducted by Navigant for DOE (Navigant 2002), and two other studies in Grays Harbor, Washington (Manclark and Nelson 1992), and Southern California (SCE 1993).

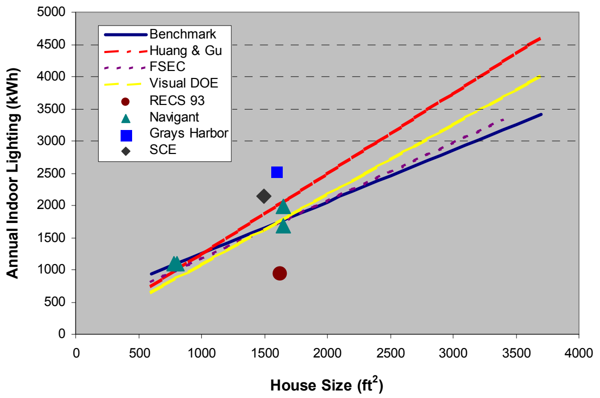


Figure 4. Comparison of Benchmark lighting equation to other references.

Hourly lighting energy may be calculated based on a number of usage variations including day type, occupancy types, room types, and season. These individual normalized profiles can be rolled up to various levels of detail. An example of one detailed set of profiles developed by NREL is shown in Figure 5. The basic profile is derived from a draft report from Lawrence Berkeley National Laboratory (LBNL) by Huang and Gu (2002). Other profiles, including a simple annual average daily profile, are documented in the lighting spreadsheet tool posted on the Building America web site.

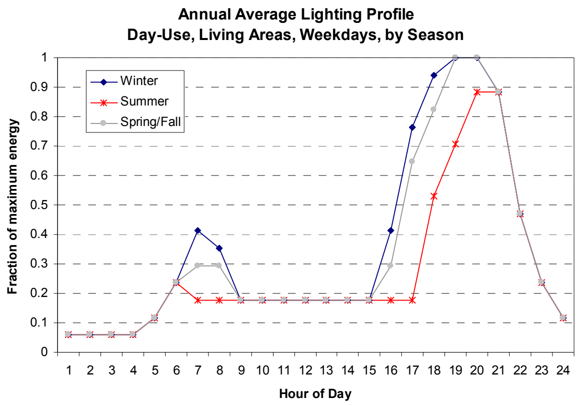


Figure 5. Example detailed lighting profile (expressed as fraction of peak daily lighting energy).

The lighting plans for the Prototype and Benchmark should be based on the same hours of operation unless the Prototype includes specific design measures that alter the operating time of the lighting system, such as occupancy sensors, dimming switches, or a building automation system. Average operating hours estimated in the Navigant study are generally a good starting point (Table 3), but there may be substantial differences between typical lighting designs found in the TPU sample and the lighting design developed in conjunction with the architecture of the Prototype. The analyst must ultimately apply good engineering judgment when specifying operating hours for the lighting system.

Table 3. Example lighting operating hours for common room types (Navigant 2002) .

Room Type	**Operation (Hours/day/ room)**	**Room Type**	**Operation (Hours/day/ room)**
Bathroom	1.8	Kitchen	3.0
Bedroom	1.1	Living Rm	2.5
Closet	1.1	Office	1.7
Dining Rm	2.5	Outdoor	2.1
Family Rm	1.8	Utility Rm	2.0
Garage	1.5	Other	0.8
Hall	1.5		

Appliances and Other Plug Loads

In order to accurately simulate appliances and other plug loads, several characteristics must be defined: the amount of the load, the schedule of the load, the location of the load, the fraction of the load that becomes a sensible load, and the fraction of the load the becomes a latent load. Though the internal load may be treated as an aggregate, the energy consumption for each end-use must be considered separately. The breakdown of annual energy consumption and associated internal loads for major appliances and other equipment is shown in Table 4. Not all of the energy consumed by appliances is converted into internal load; much of the waste heat is exhausted to the outside or released down the drain in the form of hot water. The appliance loads were derived by NREL from a combination of the default values used in the Home Energy Saver software (Pinckard 2003) and from an examination of EnergyGuide labels for typical models available on the market.

Table 4. Annual appliance and equipment loads for the Benchmark.

Appliance	Electricity (kWh/yr)	Natural Gas (therms/yr)	% Sensible Load	% Latent Load
Refrigerator	669		100	0
Clothes Washer	52.5+ 17.5xN_{br}		80	0
Clothes Dryer (Electric)	418+ 139xN_{br}		15	5
Clothes Dryer (Gas)	38+ 12.7xN_{br}	36+ 12.0xN_{br}	100 (Elect) 10 (Gas)	0 (Elect) 5 (Gas)
Dishwasher	103+ 34.3xN_{br}		60	15
Range (Electric)	604		40	30
Range (Gas)		78	30	20
Other Appliance & Plug Loads	1.67xFFA		90	10

For a house of typical size (1000-3000 ft^2), the loads from occupants and most appliances are assumed to be a function of number of bedrooms. The exceptions are refrigerator and cooking loads, which are assumed constant regardless of number of bedrooms. The "Other Appliance & Plug Loads" end-use is assumed to be a function of finished floor area. This function brings the total internal sensible load (including heat gain from occupants) approximately into line with the equation used to calculate internal loads in the International Energy Conservation Code (IECC) (ICC 2003). The sensible load for a typical 1800 ft^2, three-bedroom Benchmark (73,052 Btu/day) is also approximately the same as the constant internal sensible load value of 72,000 Btu/day specified in the HERS guidelines (RESNET 1999). Table 4 also reconciles latent load for a typically sized house with 20% of the sensible load, as specified in the HERS Guidelines. The IECC is silent on latent load.

The hourly normalized load shape for interior residential equipment use is shown in Figure 6 (Huang and Gu 2002). The equipment profile is the sum of individual profiles of each piece of equipment, some of which are nearly constant (such as refrigerator and transformer loads) and some of which are highly dependent on time-of-day (such as the range and dishwasher). NREL is in the process of developing hourly profiles for individual appliances. In the meantime, the equipment profile in Figure 6 is used for either individual appliances or equipment in aggregate. Internal sensible and latent loads from equipment should also be modeled using this profile. Appliance loads may be modeled in either the living spaces or bedroom spaces depending on their location in the Prototype.

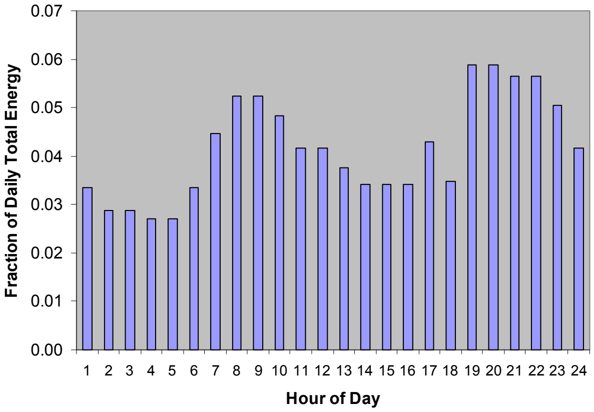


Figure 6. Interior Residential Equipment Profile

Site Electricity Generation

Based on a review of data from the Energy Information Administration (DOE 2001a), it can be concluded that there is rarely any site electricity generation in a 1990s vintage house. This is a reflection of the low market penetration of site electricity systems. Therefore, all electricity is purchased from the local utility in the Benchmark. As costs for photovoltaic systems and other site electricity systems continue to decline, they are expected to begin to make a significant contribution toward meeting residential energy needs by the year 2020. Therefore, it is important that site electricity generation be included in the analysis of whole-house energy performance.

CALCULATING ENERGY SAVINGS FOR ALL END-USES

Building America Standard Operating Conditions

The following standard operating conditions and other assumptions apply to both the Prototype house and the Benchmark. These operating conditions are largely derived from existing references, and supplemented by the cumulative experience of the authors through their work on Building America, Zero Energy Homes, Codes and Standards, and other residential energy efficiency programs. The primary differences between the Building America operating conditions and the HERS operating conditions are summarized in Table 5.

Table 5. Key differences between Building America and HERS operating conditions

Operating Condition	HERS	Building America
Set-up/ set-back	5°F if programmable thermostat	No set-up or set-back assumed because of high variability in energy savings, perceived comfort, and occupant behavior (Pigg and Nevius 2000)
Sensible and latent load	3000 Btu/hr sensible, 600 Btu/hr latent	Function of appliances, lighting, # of bedrooms, occupancy profile (see Tables 4 and 6, Figure 7)
Natural ventilation (window operation)	None	50% probability during cooling season if outside temperature is below indoor, 5-7 ACH due to open windows
Interior window shading	0.8 during cooling season, 1.0 other times	0.7 during cooling season, 0.85 all other times
Hot water (gallons/day)	$30+10xN_{Br}$	Function of N_{br}, climate, appliances, hourly profile (see Table 2, Figures 2 and 3)
Heating/ cooling seasons	Undefined	Function of monthly average temperatures
Hot water setpoint	Undefined	120°F

The occupancy schedule is defined at the same level of detail as other internal load profiles. For typical Building America houses the number of occupants is assumed to be equal to the number of bedrooms. Sensible and latent gains are accounted for separately, and different loads are applied in different space types. The peak sensible and latent heat gains from occupants, as shown in Table 6, are based on ASHRAE recommendations for different areas of the house (ASHRAE 2001).

Detailed hourly profiles for various day types, family-types, and room-types were developed by NREL based on experience and engineering judgment, and are available in spreadsheet form on the Building America web site. An example of a detailed set of occupancy profiles is shown in Figure 7.

Table 6. Peak sensible and latent heat gains from occupants.

Living Area Sensible Gain:	230	BTU/person/hr
Bedroom Area Sensible Gain:	210	BTU/person/hr
Living Area Latent Gain:	190	BTU/person/hr
Bedroom Area Latent Gain:	140	BTU/person/hr

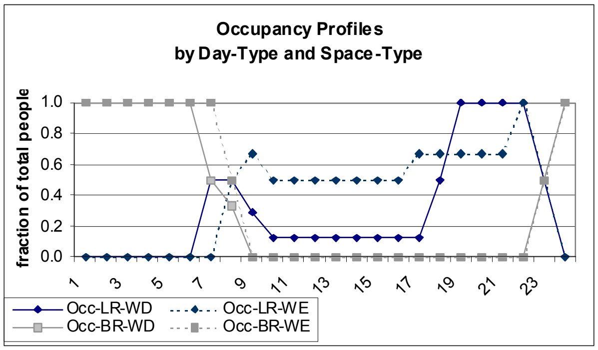


Figure 7. Example detailed hourly occupant load profile. (16.5 hours/day/occupant, number of occupants = number of bedrooms, LR = living space, BR = bedroom space, WD = weedkay, WE = weekend).

Simulating a Prototype Research House

The Prototype house is modeled either as designed or as-built, depending on the status of the project. All parameters for the Prototype house model are based on final design specifications or measured data, with the exceptions and clarifications discussed in the following paragraphs.

Natural infiltration rate is calculated using blower door measurements in accordance with ASHRAE Standard 119, Section 5.1 (ASHRAE 1988). If air leakage measurements have not been made, but a target level of natural infiltration has been established as a quality control measure, then this target level of can be used. Otherwise, the natural infiltration is the same as that used in the Benchmark model.

Mechanical ventilation must be in compliance with the total CFM requirement specified in ASHRAE Standard 62.2 (ASHRAE 2003). If the prototype house ventilation system does not meet this standard, then the model should include a small continuous exhaust or supply ventilation fan (whichever is appropriate for the climate) to make up the difference. The total fan energy is the sum of the installed fan energy and the additional fan energy calculated using Equation 6. The interactive effects of natural infiltration and the total mechanical ventilation is estimated using the guidelines in ASHRAE Standard 136 (ASHRAE 1993).

(6) Additional simulated ventilation fan energy (kWh/yr) = 3.94 x additional CFM needed to meet ASHRAE 62.2

The installation of energy-saving appliances or other equipment may reduce hot water consumption for certain end-uses, reduce the internal sensible and latent loads, or affect the hourly operating profile. Energy savings calculations for the Prototype should take these effects into account, based on rules developed for the Department of Energy residential appliance standards (DOE 2003) which underlie the many of the Benchmark appliance specifications. For example, the cycles per year specified in the appliance standards for clothes washers and dryers are adjusted based on the number of bedrooms and clothes washer capacity for the Prototype using Equations 7 and 8:

(7) Clothes washer cycles per year = $(392) \times (½ + N_{br}/6) \times 12.1\ \text{lb} / W_{test}$

where: W_{test} = maximum test load weight found in 10 CFR part 430, Subpt B, Appendix J1, as a funcion of the washer capacity in ft^3.

(8) Dryer cycles per year = Clothes washer cycles per year * DUF

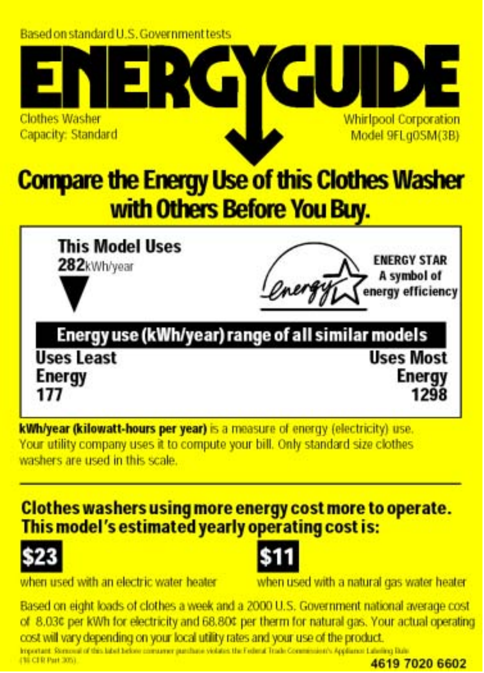
where: DUF = Dryer Use Factor = 0.84

A similar adjustment is made for the dishwasher using Equation 9:

(9) Dishwasher cycles per year = $(215) \times (½ + N_{br}/6)$

An appliance spreadsheet posted on the Building America website includes two tabs to help analysts calculate energy savings for efficient clothes washers, clothes dryers, and dishwashers. It calculates the split between hot water and machine energy based on the EnergyGuide label (Figure 8), estimates dryer energy savings for clothes washers that minimize remaining moisture content, adjusts energy use for the fact that both hot water and cold water temperatures for the Prototype are different than the test values (140ºF and 60ºF/50ºF), and adjusts for the type of controls present (thermostatic control valves, boost heating, cold water only).

Lighting energy use for the Prototype is the same as the Benchmark unless the team develops a comprehensive set of lighting specifications that addresses both builder hardwired and occupant controlled lighting fixtures. Negative and positive effects on the space conditioning load caused by energy efficient lighting should be considered, assuming 100% of interior lighting energy contributes to internal sensible load.



Based on standard U.S. Government tests

ENERGYGUIDE

Clothes Washer
Capacity: Standard

Whirlpool Corporation
Model 9FLg0SM(3B)

Compare the Energy Use of this Clothes Washer with Others Before You Buy.

This Model Uses
282kWh/year

ENERGY STAR
A symbol of energy efficiency

Energy use (kWh/year) range of all similar models

Uses Least Energy	Uses Most Energy
177	1298

kWh/year (kilowatt-hours per year) is a measure of energy (electricity) use. Your utility company uses it to compute your bill. Only standard size clothes washers are used in this scale.

Clothes washers using more energy cost more to operate. This model's estimated yearly operating cost is:

$23	**$11**
when used with an electric water heater	when used with a natural gas water heater

Based on eight loads of clothes a week and a 2000 U.S. Government national average cost of 8.03¢ per kWh for electricity and 68.80¢ per therm for natural gas. Your actual operating cost will vary depending on your local utility rates and your use of the product.

Important: Removal of this label before consumer purchase violates the Federal Trade Commission's Appliance Labeling Rule (16 CFR Part 305)

4619 7020 6602

Figure 8. EnergyGuide label for an Energy Star clothes washer.

Large end-uses in the prototype that are not part of typical houses (such as swimming pools, jacuzzis, workshops, etc.) are not included in the models for either the Prototype or Benchmark. The efficiency of these end-uses should be addressed in a separate analysis.

For Prototype research houses, all site electricity generation is credited regardless of energy source. Residential scale photovoltaic systems, wind turbines, fuel cells, and micro-cogen systems are all potential sources for site electric generation. An offset should be applied to this electricity credit equal to the amount of purchased energy used in the on-site generation process. Site generation is tracked separately in the whole-house energy analysis, and its contribution is counted towards whole-house energy savings in addition to the 40-70% savings that is targeted through use of energy efficiency improvements.

CONCLUSION

The Building America Research Benchmark was developed to allow the repeatable analysis of whole-house energy savings for Prototype research houses. To verify that the Benchmark (and energy savings calculated relative to the Benchmark) is realistic, simulated energy use for the Benchmark was compared to typical whole-house energy data compiled by the Energy Information Administration (EIA) in its 2001 RECS (DOE 2001b), as shown in Figure 9. Whole-house energy consumption matches very closely, but it appears that space cooling may be somewhat overestimated for the Benchmark. Perhaps this is because the thermostat set point is always maintained during the cooling season in the Benchmark model, while in real homes people don't always turn on the air conditioner when the temperature is above 78ºF. However, it is also possible that the RECS linear regression analysis underestimates cooling energy, which may be a very nonlinear phenomenon as a function of cooling degree-days.

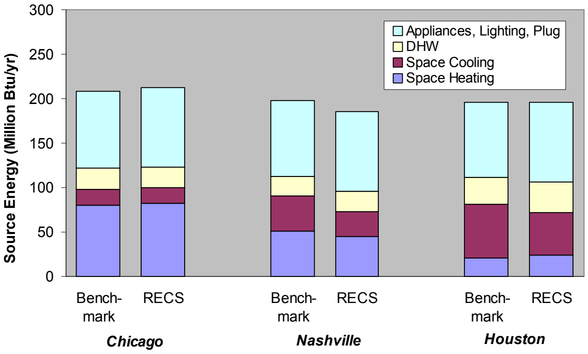


Figure 9. Comparison of Benchmark to typical 1800 ft^2 house built in the 1990s based on RECS 2001.

We believe this first attempt to develop a comprehensive point of reference for whole-house energy usage is a useful tool for analysts seeking to quantify energy savings that are often difficult to calculate in a meaningful way, such as fluorescent lighting and Energy Star appliances. NREL is currently working with the Building America teams and other stakeholders (including the energy code and voluntary rating communities) to further improve and refine the Benchmark as new information becomes available.

ACKNOWLEDGMENTS

The authors would like to thank Ron Judkoff, Jay Burch, Nancy Wells, and Paul Norton of NREL's Center for Buildings and Thermal Systems, along with Blaise Stoltenberg and Ed Hancock for their valuable contributions. In addition, the seven Building America teams provided crucial practical and technical feedback. We would also like to gratefully acknowledge the additional contributions of the rating community, including the support and contributions of Steve Baden of RESNET and Philip Fairey of FSEC. Finally, we want to express our gratitude to Ed Pollock and George James of the U.S. Department of Energy for the leadership and resources needed to complete this work.

REFERENCES

Abrams, D.W., and Shedd, A.C. 1996. Effect of Seasonal Changes in Use Patterns and Cold Inlet Water Temperature on Water Heating Load, ASHRAE Transactions, AT-96-18-3, Atlanta, GA.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers. 1988. Air Leakage Performance for Detached Single-Family Residential Buildings, ASHRAE Standard 119-1988, Atlanta, GA.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers. 1993. A Method of Determining Air Change Rates in Detached Dwellings, ASHRAE Std 136-1993, Atlanta, GA.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers. 1999. HVAC Applications Handbook, ASHRAE, Atlanta, GA.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers. 2001. Fundamentals Handbook, ASHRAE, Atlanta, GA.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers. 2003. Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings, ASHRAE Standard 62.2-2003, Atlanta, GA.

Building Science Corporation (BSC). 2004. 40-60% Prototype Performance Evaluation, Deliverable KAAX-3-32443-3.B.2, BSC, Westford, MA.

Burch, J., and Salasovich, J. 2002. Flow Rates and Draw Variability in Solar Domestic Hot Water Usage, ASES, NREL, Golden, CO.

California Energy Commission. 2002. California Building Energy Efficiency Standards, Part 1, Measure Analysis and Life Cycle Cost, CEC, Sacramento, CA.

Christensen, C., Barker, G., and Thornton, J. 2000. Parametric Study of Thermal Performance of Integral Collector Storage Solar Water Heaters, ASES, NREL, Golden, CO.

Eley Associates. 2002. Visual DOE Version 3.1, Eley Associates, San Francisco, CA.

Hendron, R., Anderson, R., Judkoff, R., Christensen, C., Eastment, M., Norton, P., Reeves, P., Hancock, E. 2004. Building America Performance Analysis Procedures, Rev. 1, NREL/TP-550-35567, NREL, Golden, CO.

Huang, J., and Gu, L. 2002. Prototypical Residential Buildings to Represent the US Housing Stock, LBNL, Berkeley, CA. (Draft)

International Code Council (ICC). 2003. International Energy Conservation Code 2003, ICC, Falls Church, VA.

Lawrence Berkeley National Laboratory (LBNL). 2000. Home Energy Saver, LBNL, Berkeley, CA.

Manclark, B., and Nelson, M. 1992. The Grays Harbor PUD Compact Fluorescent Maximization Study, Grays Harbor PUD, Grays Harbor, WA.

Navigant Consulting. 2002. U.S. Lighting Market Characterization, Navigant Consulting Inc., Washington, DC.

Parker, D. 2002. Research Highlights From A Large Scale Residential Monitoring Study In A Hot Climate, FSEC-PF369-02, FSEC, Cocoa, FL.

Pigg, S., and Nevius, M. 2000. Energy and Housing in Wisconsin: A Study of Single-Family Owner-Occupied Homes, Energy Center of Wisconsin, Madison, WI.

Pinckard, M., Brown, R., Lutz, J., Mills, E., Moezzi, M., and Atkinson, C. 2003. Documentation of Calculation Methodology and Input Data for the Home Energy Saver Web Site, LBNL, Berkeley, CA.

Residential Energy Services Network (RESNET). 1999. National Home Energy Rating Technical Guidelines, RESNET, San Diego, CA.

Southern California Edison (SCE). 1993. Final Report: Residential Lighting Study (Inventory Results), SCE, Rosemead, CA.

U.S. Department of Energy (DOE). 1996. Residential Lighting Use and Potential Savings, DOE/EIA-0555(96)/2, DOE, Washington, DC.

U.S. Department of Energy (DOE). 2001a. Annual Energy Outlook 2002, DOE, Washington, DC.

U.S. Department of Energy (DOE). 2001b. Residential Energy Consumption Survey, DOE, Washington, DC.

U.S. Department of Energy (DOE). 2003. Appliances and Commercial Equipment Standards, DOE, Washington, DC.

U.S. Department of Housing and Urban Development (HUD). 1982. “Minimum Property Standards for One- and Two-Family Living Units”, No. 4900.1-1982.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
August 2004

2. REPORT TYPE
Conference Paper Preprint

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Development of an Energy Savings Benchmark for All Residential End-Uses: Preprint

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
R. Hendron, R. Anderson, C. Christensen, M. Eastment, and P. Reeves

5d. PROJECT NUMBER
NREL/CP-550-35917

5e. TASK NUMBER
BET4.8004

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/CP-550-35917

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*

CP-CP-550-35917To track progress toward aggressive multi-year whole-house energy savings goals of 40-70% and onsite power production of up to 30%, the U.S. Department of Energy (DOE) Residential Buildings Program and the National Renewable Energy Laboratory (NREL) developed the Building America Research Benchmark in 2003. The Benchmark is generally consistent with mid-1990s standard practice, as reflected in the Home Energy Rating System (HERS) Technical Guidelines, with additional definitions that allow the analyst to evaluate all residential end-uses, an extension of the traditional HERS rating approach that focuses on space conditioning and hot water. A series of user profiles, intended to represent the behavior of a “standard” set of occupants, was created for use in conjunction with the Benchmark. Finally, a set of tools was developed by NREL and other Building America partners to help analysts compare whole-house energy use for a Prototype house to the Benchmark in a fair and consistent manner.

15. SUBJECT TERMS
Building America; energy-efficient houses; U.S. Department of Energy; DOE; Performance Analysis Procedures; benchmarking

16. SECURITY CLASSIFICATION OF:

a. REPORT	b. ABSTRACT	c. THIS PAGE
Unclassified	Unclassified	Unclassified

17. LIMITATION OF ABSTRACT
UL

18. NUMBER OF PAGES

19a. NAME OF RESPONSIBLE PERSON

19b. TELEPONE NUMBER (*Include area code)*