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WHOLE-HOUSE ENERGY ANALYSIS PROCEDURES FOR EXISTING HOMES

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ABSTRACT

This paper describes a proposed set of guidelines for analyzing the energy savings achieved by a package of retrofits or an extensive rehabilitation of an existing home. It also describes certain field test and audit methods that can help establish accurate building system performance characteristics that are needed for a meaningful simulation of whole-house energy use. Several sets of default efficiency values have been developed for older appliances that cannot be easily tested and for which published specifications are not readily available. These proposed analysis procedures are documented more comprehensively in NREL Technical Report TP-550-38238 (Hendron 2006).

INTRODUCTION

Because there are more than 101 million residential households in the United States today, it is not surprising that existing residential buildings represent an extremely large source of potential energy savings. Building America (BA) is investigating the best ways to make existing homes more energy-efficient, based on lessons learned from research on new homes. The research goals for BA include developing retrofit packages that can achieve a 20% reduction in energy use in existing homes by 2015 and a 30% reduction by 2025. Research activities include a combination of computer modeling, field demonstrations, and long-term monitoring to support the development of integrated approaches to reduce energy use in existing residential buildings. Also, DOE partners with the U.S. Environmental Protection Agency to increase energy efficiency in existing homes through Home Performance with ENERGY STAR®.

GENERAL ANALYSIS APPROACH

The general approach to modeling whole house energy savings for retrofits of existing homes is intended to complement similar guidelines developed by BA for new home construction, including the Building America Research Benchmark (Hendron 2005), more commonly referred to simply as the Benchmark. Most of the simulation tools that are useful for residential new construction are also applicable to residential retrofit analysis. Certain tools such as TREAT offer additional features such as side-by-side comparisons, automated efficiency package recommendations, and utility bill analysis/reconciliation. Further information about TREAT and a number of other useful tools for retrofit analysis of residential buildings can be found in the DOE Energy Software Tools Directory (www.eere.energy.gov/buildings/tools_directory/).

It is not recommended that utility bills be heavily relied upon as a tool for model calibration, except as an approximate check of model accuracy. There are two important reasons for this position:

- It is extremely difficult to accurately determine occupant behavior during the time period reflected in the utility bills.
- The large number of uncertain input parameters allows multiple ways to reconcile the model with the small number of utility bills, and no reliable methodology exists for performing this calibration because the problem is fundamentally mathematically undetermined.

Instead, detailed inspections, short-term testing, and long-term monitoring should be utilized to the greatest extent possible to minimize the uncertainty in model inputs. Default values may be used when certain building features are inaccessible (wall insulation) or efficiency characteristics cannot be readily determined through inspection or short-term testing (furnace AFUE). The effects of maintenance and repairs should always be considered when using default values for equipment efficiency or the amount of insulation.

Throughout the remainder of this paper, the term "Pre-Retrofit Case" refers to the state of an existing house immediately before it undergoes a series of upgrades, repairs, additions, or renovations. These measures may be limited to a focused set of energy efficiency improvements to the house or may be part of a larger remodeling or gut rehabilitation effort. The term "Post-Retrofit Case" refers to the same existing house after the package of improvements is complete.

MODELING THE PRE-RETROFIT CASE

Any element of the Pre-Retrofit Case that is not specifically addressed in the following sections, or is not changed as part of the package of energy efficiency measures, is assumed to be the same as the Post-Retrofit Case. To the extent possible, all building envelope components (including walls, windows, foundation, roof, and floors) for the Pre-Retrofit Case are based on physical inspections, audits, design specifications or measured data. Co-heating tests (Judkoff et al. 2000) or infrared imaging during cold weather may provide some useful information about the insulation quality without damaging the building envelope, but in most retrofit scenarios these tests are overly expensive and would not provide data that could be easily factored into a building simulation.

If detailed envelope characteristics cannot be obtained, the following default specifications may be used:

- R-values for cavity insulation in exterior 2x4 or 2x6 wood frame walls from Table 1.
- R-values for cavity insulation in floors over unconditioned space from Table 2.
- Insulation thickness in all other locations is measured, and the default R-values per inch in Table 3 are applied.

Table 1 Default R-values for wall cavity insulation (based in part on Huang and Gu 2002)

Wall Construction Type	Year of Construction			
	Post 1990	1980-89	1950-79	Pre 1950
2x4, 16-in. o.c.	13	11	9	7
2x6, 24-in. o.c.	19	17	15	13

Table 2 Default R-values for floors above unconditioned space (based in part on Huang and Gu 2002)

Building America Climate Region	Year of Construction			
	Post 1990	1980-89	1950-79	Pre 1950
Cold, Very Cold, Subarctic, Marine	19	17	15	13
All Others	0	0	0	0

Table 3 Default R-value for common insulation types (DOE 2003, E-Star Colorado 2005)

Insulation Material	Year of Construction	
	1990 or after	Before 1990
High density fiberglass batt	3.8/in.	3.0/in.
Low density fiberglass batt	2.7/in.	2.0/in.
Loose fill fiberglass	3.2/in.	2.5/in.
Cellulose (blown, wet or dry)	3.7/in.	3.4/in.
Expanded polystyrene (EPS)	4.0/in.	3.8/in.
Extruded polystyrene (XPS)	5.0/in.	4.8/in.
Open cell polyurethane foam	3.6/in.	3.3/in.
Closed cell polyurethane foam	6.5/in.	5.9/in.
Rigid polyisocyanurate	7.2/in.	5.8/in.

- Default U-values for vertical fenestration, including windows and sliding glass doors, from Table 4 in Chapter 31 of the 2005 American Society of Heating, Refrigerating, and Air-Conditioning Engineers Handbook of Fundamentals (ASHRAE 2005).
- Total assembly solar heat gain coefficient (SHGC) for vertical fenestration from Table 13 in Chapter 31 of the 2005 ASHRAE Handbook of Fundamentals (ASHRAE 2005).
- Default solar absorptivity equal to 0.50 for opaque areas of exterior walls and 0.75 for opaque areas of roofs.
- Default infrared emittance of exterior walls and roofs equal to 0.90.
- The default framing factors in Table 4 may be used for houses using wood construction.

Table 4 Default wood-framing factors

Enclosure Element	Frame Spacing (inches o.c.)	Framing Fraction (% area)
Walls	16	23%
Floors	16	13%
Ceilings	24	11%

To the extent possible, the performance characteristics (efficiency and capacity) of all space-conditioning components (including heating system, cooling system, dehumidification, air handler, and ducts) for the Pre-

Retrofit Case are based on physical inspections, audits, design specifications, and measured data. An estimate of Annual Fuel Utilization Efficiency (AFUE) for a furnace or Heating Seasonal Performance Factor (HSPF) for a heat pump can be obtained with reasonable accuracy by performing a co-heating test to determine the building loss coefficient (Judkoff et al. 2000), then measuring the gas or electricity input over a period of time with known inside and outside temperatures. Field-audit procedures for heating equipment have also been developed by LBNL (Szydlowski and Cleary 1988). Cooling efficiency is much more difficult to measure directly as part of a short-term test, and in most cases the manufacturer's published data should be used.

If Pre-Retrofit space-conditioning system characteristics are unknown or unavailable, default specifications may be used. The tables of defaults provided in this paper are abridged versions of more complete tables included in the full NREL report (Hendron 2006) and include some of the more common types of equipment.

Default furnace or boiler system efficiency may be calculated using Equation 1 in conjunction with the parameters in Table 5 if the actual efficiency of the equipment is unknown and cannot be readily obtained through field-testing (for example if the audit is conducted in the summer, the heating system is broken, or testing would be cost-prohibitive). Typical base values for AFUE were obtained from the ASHRAE HVAC Systems and Equipment Handbook (ASHRAE 2004a), the 1987 EPRI Technical Assessment Guide (EPRI 1987), and the Technical Support Documents for the National Appliance Energy Conservation Act (NAECA) appliance standards (DOE 2004a). Estimates of degradation rates are partly based on the E-Source Space Heating Technology Atlas (E-Source 1993).

$$\text{AFUE} = (\text{Base AFUE}) * (1\text{-M})^{\text{age}} \qquad (1)$$

Where: Base AFUE = Typical efficiency of Pre-Retrofit equipment when purchased

M = Maintenance Factor
Age = Age of equipment in years.

For example, the default AFUE for a 10-year-old, poorly maintained oil furnace with a conventional burner would be calculated as follows:

$$\text{AFUE} = (71) * (1\text{-}0.025)^{10} = 55\%.$$

Auxiliary electricity use for furnaces and boilers, including blowers and controls, is measured directly if possible. If accurate measurements cannot be made, the default values of auxiliary electricity use in Table 6 may be used.

The default air conditioner and heat pump efficiencies in Table 7 may be used if the actual efficiency cannot be calculated or measured. Base values for Seasonal Energy Efficiency Ratio (SEER), Energy Efficiency Ratio (EER), and Heating Seasonal Performance Factor (HSPF) were obtained from the engineering analysis of appliance standards for air conditioners and heat pumps (DOE 2002), and from the LBNL Energy Data Sourcebook (Wenzel et al. 1997). Adjustments to efficiency related to age and quality of maintenance are applied in accordance with Equation 2. Performance degradation rates for cooling systems are based in part on a study done by LBNL for the California Energy Commission (Matson et al. 2002).

$$\text{EFF} = (\text{Base EFF}) * (1\text{-M})^{\text{age}} \qquad (2)$$

Where: Base EFF = Typical efficiency of Pre-Retrofit equipment when purchased (SEER, EER, or HSPF)
M = Maintenance Factor
Age = Age of equipment in years.

For houses with air ducts, the Pre-Retrofit Case is modeled using data collected through visual inspections, physical measurements, and duct leakage testing. Default values for duct leakage are not used. Duct-blaster testing is conducted in accordance with American Society for Testing of Materials (ASTM) Standard E1554 (ASTM 1994). Tracer-gas testing of the air-distribution system is encouraged when possible and is conducted in accordance with NREL Performance Test Practices for duct systems (Hancock et al. 2002).

Table 5 Example default furnace and boiler system efficiencies (data excerpted from Hendron 2006). "Gas" refers to either natural gas or propane.

Type of Space Heating Equipment	**Base AFUE**[1]	**Maintenance Factor (M)**	
		Annual Professional Maintenance	**Seldom or Never Maintained**
Condensing gas furnace	90	0.005	0.015
Gas furnace, direct vent or forced draft combustion, electronic ignition, in conditioned space	80	0.005	0.015
Gas furnace, natural draft combustion, standing pilot light, no vent damper, in unconditioned space	64	0.005	0.015
Gas hot water boiler, natural draft combustion, standing pilot light	80	0.005	0.015
Gas hot water / fan coil combo system	80	0.005	0.015
Gas space heater, fan type	73	0.005	0.015
Oil furnace, flame retention burner, vent dampers, in conditioned space	81	0.01	0.025
Oil furnace, conventional burner, no vent dampers, in conditioned space	71	0.01	0.025
Oil steam boiler	82	0.01	0.025
Electric resistance furnace or boiler, conditioned space	100	0	0

Table 6 Example default electricity consumption for heating-system blowers and other auxiliary heating equipment (data excerpted from Hendron 2006).

Type of Heating Equipment	**Electricity/ Capacity**
Gas furnace (including mobile home furnace)	9.2 (kWh/yr)/ (kBtu/hr)
Gas hot water boiler with hydronic distribution	1.1 (kWh/yr)/ (kBtu/hr)
Oil furnace	8.0 (kWh/yr)/ (kBtu/hr)
Electric furnace	Included in AFUE

Table 7 Example default air-conditioning and heat-pump efficiencies (data excerpted from Hendron 2006).

Type of Air Conditioning (A/C) or Heat Pump Equipment	**Base SEER**	**Base EER**	**Base HSPF**	**Maintenance Factor (M)**	
				Annual Professional Maintenance	**Seldom or Never Maintained**
Split central A/C, two-speed reciprocating compressor, ECM blower motor, thermostatic expansion valve (TXV), fan coil	14	10.5		0.01	0.02
Split central A/C, single-speed reciprocating compressor, PSC blower motor, cased coil, pre-1981	6.5	6.4		0.01	0.03
Split heat pump, single-speed scroll compressor, ECM blower motor, TXV valve	14	10.5	8.0	0.01	0.03
Split heat pump, single-speed reciprocating compressor, PSC blower motor, pre-1981	6.5	6.4	6.0	0.01	0.03
Packaged central A/C, single-speed reciprocating compressor, PSC blower motor	10	9.1		0.01	0.03
Room A/C, louvered sides, cooling only, single-speed compressor, PSC fan motor, pre-1981		6.5		0.01	0.03
Direct evaporative cooling		25		0.02	0.05

[1] Combined Appliance AFUE (CA_{AFUE}) for combo systems

To the extent possible, the specifications of the domestic hot water (DHW) system in the Pre-Retrofit Case are based on audits, design specifications, physical measurements, and test data. Published data from the manufacturer provides the most reliable estimate of energy factor (EF), because in-situ testing introduces several variables (such as water-use profile and ambient temperature) that usually make a reliable measurement of standby losses impossible. The procedures to measure recovery efficiency and standby losses described by LBNL (Szydlowski and Cleary 1988) may be used in conjunction with the NREL tank loss spreadsheet to give a rough estimate of the EF (www.eere.energy.gov/buildings/building_america/docs/tankloss.xls). If the EF of the equipment cannot be determined through measurement or examination of the published performance data, the default specifications in Table 8 may be used, with age and maintenance adjustments in accordance with Equation 3. These defaults were largely derived from technical support documents for the Federal appliance standard for water heaters (DOE 2000a).

$$EF = (\text{Base EF}) * (1\text{-}M)^{age} \quad (3)$$

Where: Base EF = Typical energy factor of Pre-Retrofit equipment when purchased
M = Maintenance Factor
Age = Age of equipment in years

Table 8 Default DHW energy factors. "Gas" refers to either natural gas or propane.

Type of Water Heating Equipment	Base Energy Factor (EF)	Maintenance Factor (M)	
		Annual Professional Maintenance	Seldom or Never Maintained
Gas water heater, 40-gal tank, pilot light, natural draft combustion, poorly insulated, no heat traps, poor heat recovery from flue	0.45	0.005	0.01
Gas water heater, 40-gal tank, intermittent ignition, forced draft combustion, 3-in. insulation, heat traps, enhanced flue baffling, flue/vent dampers	0.64	0.005	0.01
Gas instantaneous water heater	0.80	0.005	0.01
Oil water heater, 32-gal tank, intermittent ignition, forced-draft combustion, poorly insulated, no heat traps, poor heat recovery from flue	0.53	0.005	0.01
Oil water heater, 32-gal tank, interrupted ignition, forced-draft combustion, 3-in. insulation, heat traps, enhanced flue baffling	0.61	0.005	0.01
Electric water heater, 50-gal tank, poorly insulated, no heat traps	0.79	0.001	0.002
Electric water heater, 50-gal tank, 3-in. insulation, heat traps	0.90	0.001	0.002
Electric instantaneous water heater	1.00	0	0

Four major end uses have been identified for domestic hot water: showers, sinks, dishwasher, and clothes washer. For showers and sinks, the daily volume is the same as the value defined for the Benchmark and represents the combined volume of hot and cold water. For clothes washers and dishwashers, the BA Analysis Spreadsheet developed by NREL is used to estimate the Pre- and Post-Retrofit hot-water consumption based on standard operating conditions and information listed on the EnergyGuide label. If no EnergyGuide label is available, then the default values of energy factor (EF) for dishwashers (see Table 13) or modified energy factor (MEF) for clothes washers (see Table 10) may be used for the Pre-Retrofit Case. The profiles for hourly hot water use and mains water temperature are the same as the Benchmark (Hendron 2005).

The effective leakage area for the Pre-Retrofit Case is calculated based on blower-door testing conducted in accordance with ASTM E779-03 (ASTM 2003). It is recommended that blower door measurements be supplemented with tracer-gas testing when time and resources permit.

Additional air exchange as a result of mechanical ventilation is assumed for the model of the Pre-Retrofit Case if it does not meet the ventilation guidelines of ASHRAE Standard 62.2-2004 (ASHRAE 2004b) based on natural infiltration alone. Supplemental mechanical ventilation is calculated using Equation 4, which is based on a simple continuous exhaust fan designed to raise the total ventilation rate to the minimum values specified in Equation 4.1a of ASHRAE Standard 62.2-2004, taking into account any infiltration credit allowed under Section 4.1.3. Supplemental mechanical ventilation is combined with the actual ventilation and natural infiltration in accordance with Section 4.4 of ASHRAE Standard 136

(ASHRAE 1993) to determine an approximate combined effective air change rate. The fan energy use associated with supplemental mechanical ventilation for the Pre-Retrofit case is calculated by multiplying the supplemental ventilation rate by 3.942 kWh/cfm. This energy is added to the energy used by any ventilation fan present in the house.

$$Q_{sup} = [0.01xFFA+7.5x(N_{br}+1)] - [A_IxCFAxH/60 - 2xFFA/100]/2 \quad (4)$$

Where:

Q_{sup} = supplemental mechanical ventilation assumed for the Pre-Retrofit Case (cfm)
FFA = finished floor area (ft^2)
CFA = conditioned floor area, including directly or indirectly conditioned basements (ft^2)
H = average height of one story (ft)
A_I = annual average air changes per hour as a result of natural infiltration (ACH)
N_{br} = number of bedrooms.

The total annual lighting budget for the Pre-Retrofit case is determined by conducting a detailed audit of light fixtures and lamps inside and outside the house. Operating hours may be determined through long-term monitoring or by conducting occupant interviews or surveys. If reliable estimates of operating hours cannot be obtained or calculated, then the default operating hours developed by Navigant based on a Tacoma Public Utilities lighting study (Navigant 2002) may be used (Table 9). The annual average normalized daily load shape for interior lighting is the same profile used by Building America in the context of new construction (Hendron 2005).

Table 9 Default lighting operating hours for common room types (Navigant 2002)

Room Type	Hrs/day/ room	Room Type	Hrs/day/ room
Bathroom	1.8	Kitchen	3.0
Bedroom	1.1	Living Room	2.5
Closet	1.1	Office	1.7
Dining Room	2.5	Outdoor	2.1
Family Room	1.8	Utility Room	2.0
Garage	1.5	Other	0.8
Hall	1.5		

To the extent possible, actual specifications for all major appliances should be based on manufacturer's literature or an EnergyGuide label. Spot electricity measurements may be performed for loads that are relatively constant when operating, such as refrigerators and freezers. A more standardized procedure for calculating average daily electricity use for refrigerators was developed by Lawrence Berkeley National Laboratory (Szydlowski 1988).

If EnergyGuide labels are available for dishwashers and clothes washers, then the BA Analysis Spreadsheet can be used to estimate annual energy use. If EnergyGuide labels cannot be located or do not exist for certain major appliances (e.g., ovens and clothes dryers), the default energy factors in Tables 10 through 15 may be used. These defaults were derived from historical appliance efficiency studies (Wenzel et al. 1997, DOE 2004b, EPRI 1986) and technical support documents for recent changes to Federal appliance standards (DOE 1993, DOE 2000b).

Table 10 Default standard size (~2.5 ft^3) clothes washer characteristics

Equipment Characteristics	MEF (ft^3/kWh)
Horizontal axis, cold-rinse option, automatic fill, thermostatically controlled mixing valve, improved water extraction	1.62
Vertical axis, cold-rinse option, automatic fill, thermostatically controlled mixing valve, improved water extraction	1.02
Vertical axis, cold-rinse option, water-level option, standard mixing valve	0.64
Vertical axis, no cold-rinse option, no water-level option	0.47

Table 11 Default gas clothes dryer characteristics (assumes typical 1990 clothes washer capacity and remaining moisture content)

Equipment Characteristics	EF (lb/kWh)
Cool-down mode, intermittent ignition, automatic termination control, improved door seal, well insulated	2.67
Cool-down mode, intermittent ignition, timer control, improved door seal, well insulated	2.40
No cool-down mode, pilot light, timer control, poor door seal, poorly insulated	2.00

Table 12 Default electric clothes dryer characteristics (assumes typical 1990 clothes washer capacity and remaining moisture content)

Equipment Characteristics	EF (lb/kWh)
Cool-down mode, automatic termination control, improved door seal, well insulated	2.75
No cool-down mode, timer control, poor door seal, poorly insulated	2.60

Table 13 Default dishwasher characteristics

Equipment Characteristics	EF (load/kWh)
Power dry optional, multi-tier spray device, load size and soil level controls	0.6
Power dry optional, multi-tier spray device, no load size or soil level controls	0.43
Power dry always, single-tier spray device, no load size or soil level controls	0.24

Table 14 Default gas oven / cooktop characteristics

Equipment Characteristics	EF	Annual Energy (therms/yr)
Cooktop: intermittent ignition, sealed burner Oven: spark ignition, not self cleaning, improved door seals, reduced vent rate, high-density insulation	Cooktop: 42.0% Oven: 6.2%	Cooktop: 17 Oven: 18
Cooktop: intermittent ignition, open burner Oven: electric glo-bar ignition, self cleaning	Cooktop: 40.0% Oven: 5.8%	Cooktop: 18 Oven: 19 (+80 kWh)
Cooktop: pilot lights Oven: pilot light, not self-cleaning, standard door seals, standard vent rate, standard insulation	Cooktop: 18.8% Oven: 3.5%	Cooktop: 39 Oven: 36

Table 15 Default electric oven / cooktop characteristics

Equipment Characteristics	Energy Factor	Annual Energy (kWh/yr)
Cooktop: reflective pans, flat coil elements Oven: self-cleaning, improved door seals	Cooktop: 77.7% Oven: 10.2%	Cooktop: 270 Oven: 349
Cooktop: solid disc elements Oven: not self-cleaning, improved door seals, reduced vent rate, high density insulation	Cooktop: 74.2% Oven: 12.1%	Cooktop: 282 Oven: 293
Cooktop: non-reflective pans, rounded coil elements Oven: not self-cleaning, standard door seals, standard vent rate, standard insulation	Cooktop: 73.7% Oven: 10.9%	Cooktop: 284 Oven: 326

In most cases, Miscellaneous Electric Loads (MELs) are treated as a constant function of finished floor area, regardless of the actual MELs present in the Pre-Retrofit Case (Equation 5). Alternatively, if MEL improvements are included in the retrofit package, analysts may use the more detailed methodology developed for new construction, which allows energy savings credit for replacement of small appliances and reduction of standby losses. This methodology is documented in the BA MEL Analysis Spreadsheet (http://www.eere.energy.gov/buildings/building_america/pa_resources.html).

$$MEL = 1.49 \times FFA \times F_s \quad (5)$$

Where: MEL = miscellaneous electric loads for the Pre-Retrofit Case (kWh/yr)
FFA = finished floor area (ft^2)
F_s = state multiplier (NY=0.82, CA=0.77, FL=0.94, TX=1.11, all others=1.00).

Operating hours estimated through occupant surveys or interviews may be useful for determining the cost-effectiveness of replacing certain appliances and electronic equipment for a particular homeowner. However, the standard operating conditions specified for the Benchmark are used for the purpose of calculating and reporting whole-house energy savings for existing homes in the context of Building America. In addition, the hourly load shapes for appliances and MELs and the fraction of end-use energy converted into internal sensible and latent load are the same as the Benchmark used for new construction (Hendron 2005).

MODELING THE POST-RETROFIT CASE

The Post-Retrofit Case is modeled either as-designed or as-built, depending on the status of the project. All parameters for the Post-Retrofit model are based on final design specifications or measured data, with the following exceptions and clarifications:

- House characteristics that are unknown or not part of the package of energy efficiency improvements should be the same as the Pre-Retrofit Case.
- The effective leakage area for the Post-Retrofit Case is calculated based on blower-door testing conducted in accordance with ASTM E779. It is recommended that blower-door measurements be supplemented with tracer-gas testing if possible.
- Additional air exchange resulting from mechanical ventilation is assumed if the Post-Retrofit Case does not meet the ventilation guidelines of ASHRAE Standard 62.2-2004 based on natural infiltration alone. Supplemental mechanical ventilation is calculated using the same methodology discussed earlier in the context of the Pre-Retrofit Case.
- 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 profiles. Energy savings calculations for the Post-Retrofit Case should take these effects into account. The number of cycles per year specified in the appliance standard for clothes washers is adjusted according to the number of bedrooms and the clothes washer capacity, using Equation 6:

  $$\text{Clothes washer cycles per year} = (392) \times (½+N_{br}/6) \times 12.5\text{ lb} / W_{test} \quad (6)$$

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

  A dryer usage factor (DUF) is applied to the clothes washer cycles to determine the number of annual dryer cycles, using Equation 7:

  $$\text{Clothes dryer cycles per year} = DUF \times \text{Clothes washer cycles per year} \quad (7)$$

  Where: DUF = 0.84.

  The dishwasher (DW) annual operating cycles are similarly calculated using Equation 8:

  $$\text{DW cycles per year} = (215) \times (½ + N_{br}/6) \quad (8)$$

  The BA Analysis Spreadsheet posted on the BA web site automates these calculations and is strongly recommended for the analysis of water-consuming appliances. It calculates the split between hot water and machine energy based on the EnergyGuide label, estimates dryer energy savings for clothes washers that reduce remaining moisture content, adjusts energy use for hot water and cold water temperatures that 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).
- Energy savings for a new range/oven may only be credited if an energy factor has been determined in accordance with the DOE test procedures for cooking appliances (DOE 1993). Annual energy consumption is then estimated as the product of the energy factor and the annual useful cooking energy output as defined in the same test procedure. If the energy factor is unknown for a new range/oven, then it is assumed that the Post-Retrofit energy use for cooking is the same as the Pre-Retrofit case.
- Modifications to the Pre-Retrofit lighting profile and operating hours because of occupancy sensors or other controls may be considered for the Post-Retrofit Case, but negative and/or positive effects on space conditioning load must also be calculated, assuming 100% of interior lighting energy contributes to the internal sensible load.
- For the Post-Retrofit Case, all site electricity generation is credited regardless of energy source. Residential-scale photovoltaic systems, wind turbines, fuel cells, and micro-cogeneration systems are all potential sources of electricity generated on the site. An offset must be applied to this electricity credit equal to the amount of purchased energy used in the on-site generation process.

OPERATING CONDITIONS

The same operating conditions are applied to both the Pre- and Post-Retrofit Cases. They are intended to represent the behavior of a typical set of occupants, not the current occupants of the house, because Building America is interested in estimating long-term energy savings of improvements to existing homes. The same operating conditions used for new construction are also used for existing homes. These operating conditions are documented in the BA Benchmark Definition (Hendron 2005) and are based on the cumulative experience of the authors through their work on Building America, HERS, Codes and Standards, and other residential energy efficiency programs.

CONCLUSION

This paper provides an overview of a proposed set of guidelines for analyzing the whole-house energy savings of retrofits and renovations of existing residential buildings. These guidelines are intended to complement the procedures developed for analyzing new homes (Hendron et al. 2004), and the two sets of guidelines share many of the same elements. We expect these procedures to evolve to some extent as existing homes become a higher priority for residential buildings research, and more aggressive energy savings targets are achieved. NREL also plans to evaluate the usefulness and accuracy of these procedures as part of a community-scale retrofit project by providing support for pre-retrofit audits, energy savings calculations, and post-retrofit monitoring.

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NOMENCLATURE

AFUE	annual fuel utilization efficiency for heating systems
CA_{AFUE}	combined appliance AFUE
EER	energy efficiency ratio for cooling systems
EF	energy factor for water heaters, dishwashers, ranges, and clothes dryers
HSPF	heating seasonal performance factor
M	maintenance factor
MEF	modified energy factor for clothes washers
SEER	seasonal energy efficiency ratio for cooling systems

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