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Method for Evaluating Energy Use of Dishwashers, Clothes Washers, and Clothes Dryers

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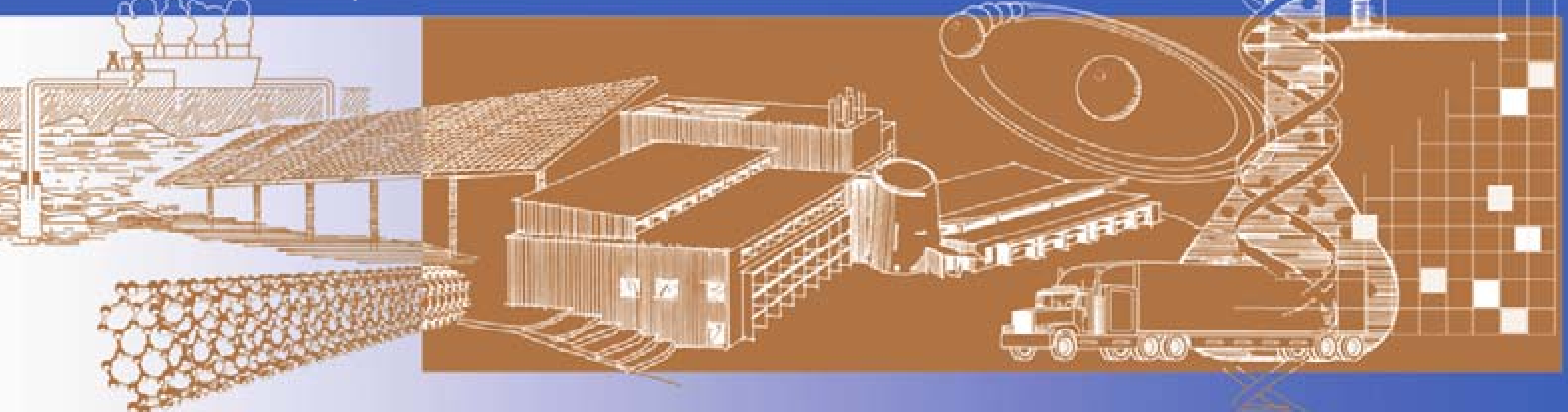

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Method for Evaluating Energy Use of Dishwashers, Clothes Washers, and Clothes Dryers[1]

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ABSTRACT

Building America teams are now researching opportunities to improve whole house energy efficiency including more challenging end-uses, such as lighting (both fixed and occupant-provided), appliances (clothes washer, dishwasher, clothes dryer, refrigerator, and range), and MELs. These end uses are all heavily dependent on occupant behavior and product choices. Part of that research is evaluating the energy savings resulting from the specification of efficient appliances in energy-efficient homes. Using DOE test procedures, the method outlined in this paper presents a reasonable way to calculate energy savings for specific dishwashers, clothes washers, and clothes dryers. The information necessary to generate these inputs is available on Energy-Guide labels, the ENERGY-STAR® website, California Energy Commission's Appliance website, and manufacturer's literature.

Introduction

The U.S. Department of Energy's (DOE) Buildings Technology Program, including such initiatives as Building America, has recently entered a new phase of research. The focus is on all residential energy uses since significant progress has already been made toward reducing space-conditioning loads in new housing in most climates in the United States. Lighting (both fixed and occupant-provided), appliances (clothes washer, dishwasher, clothes dryer, refrigerator, and range), and miscellaneous electric loads are all heavily dependent on occupant behavior and product choices and have grown to be a much more significant fraction of total household energy.

How do we estimate the effect of efficient appliances on whole-building energy consumption? Using Energy-Guide label information at face value for whole building simulations is problematic because the data is representative of test procedures designed to give consumers cost and performance data with the intent of making "apples to apples" comparisons. This type of information lacks the level of detail and location specific information necessary to be used with a whole building energy simulation. The reported annual energy consumption on Energy-Guide labels includes machine electrical energy consumption and a nominal amount of energy for water heating based on hot water volume consumed under DOE test conditions. NREL has developed a reasonable analytical method for crediting the use of efficient dishwashers, clothes washers, and clothes dryers when compared to the Building America Research Benchmark (referred to as the Benchmark, Hendron 2005) where previously Building America analysts had no standardized method for calculating energy savings related to the

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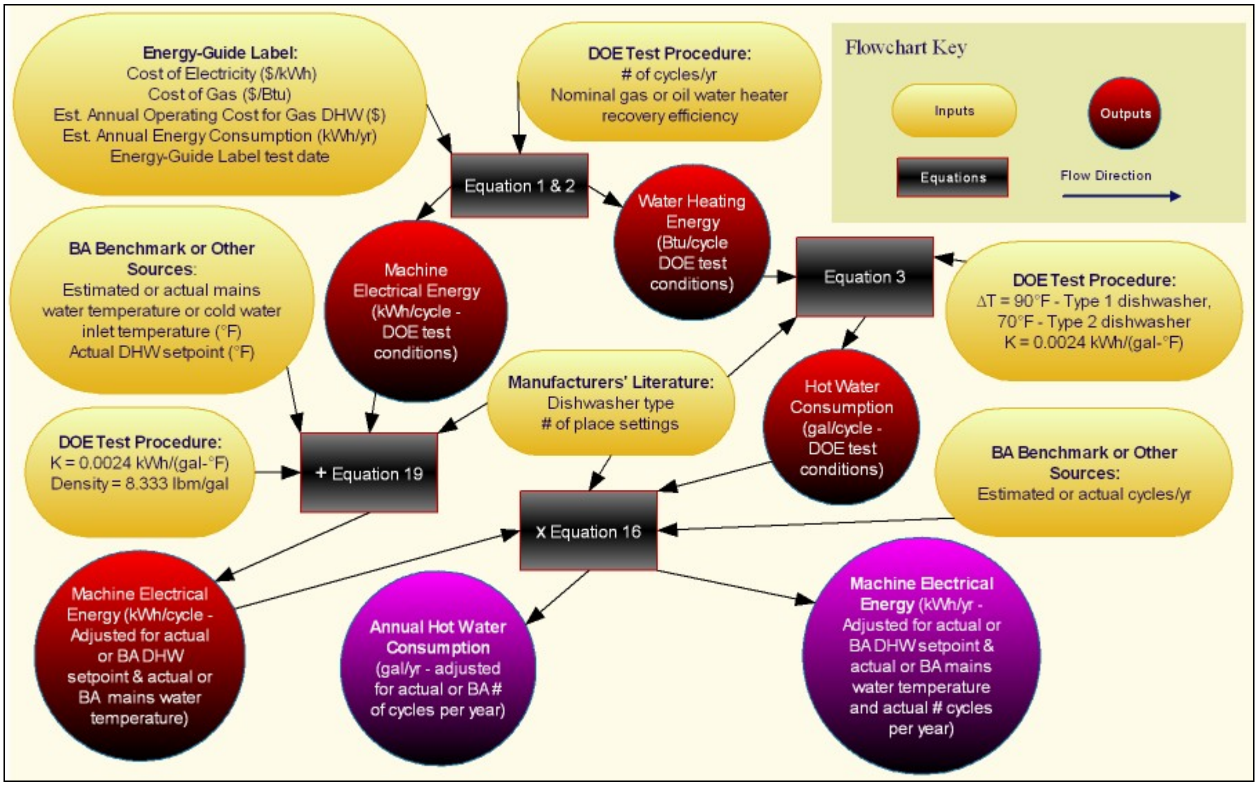
specification of efficient appliances in research homes. This method allows the user to develop inputs to whole building energy simulation tools that are sensitive to location specific design conditions and are disaggregated appropriately for use in a whole building energy simulation.

Dishwashers

Estimating the Energy and Hot Water Use of Dishwashers

Figure 1 shows the flowchart for the solution method used to determine the hot water consumption and machine electrical energy use for dishwashers.

Figure 1. Solution Method Flowchart for Dishwashers



The basic approach is to disaggregate detailed performance characteristics (machine electrical energy consumption and hot water consumption per cycle) from the overall energy use and cost data listed in the Energy-Guide label. These values are adjusted for location specific design information and Benchmark operating assumptions, which, in some cases, differ significantly from DOE test procedures.

Machine Types. To begin solving for the machine electrical energy consumption and hot water volume consumption, it is necessary to understand basic dishwasher types. The following definitions are used here:

- Type 1 dishwashers – do not heat water internally, hot water connection only
- Type 2 dishwashers – have an electric element internal to the machine for the purpose of providing auxiliary water heating, hot water connection only

- Type 3 dishwashers – have an electric element internal to the machine for the purpose of heating all of the water used to wash the dishes, cold water connection only.

In order to estimate the energy consumption of dishwashers, it is necessary to understand the underlying energy use calculations found in the 10CFR Part 430, Subpt. B, App. C (DOE 1999).

Dissagregation of Energy-Guide Label Data. These equations from DOE test procedures determine estimated operating expenses and estimated annual energy consumption as it appears on Energy-Guide labels:

A) Annual Estimated Energy Cost for Gas Water-Heating (Type 1 & 2 dishwashers when gas or oil-heated water, DOE 1999):

$$EAOC_g = N\left[\left(D_e * M\right) + \left(D_w * W\right)\right]$$ [2]

B) Annual Energy Consumption Equation:

$$E_{ann} = N\left(W * 0.000293\frac{kWh}{Btu} * e + M\right).$$ [3]

If (B) is solved for M and then is substituted into the (A), the result can be solved for energy required for water heating:

Equation 1: $$W = \frac{EAOC_g - \left(D_e * E_{ann}\right)}{N\left[D_w - \left(D_e * 0.000293\frac{kWh}{Btu} * e\right)\right]}\left(\frac{Btu}{cycle}\right).$$

Machine energy is then given by

Equation 2: $$M = \left(\frac{E_{ann}}{N}\right) - \left(W * 0.000293\frac{kWh}{Btu} * e\right)\left(\frac{kWh}{cycle}\right).$$

To estimate the hot water volume consumed:

Equation 3: $$GHW = \frac{W}{K * \Delta T}\left(\frac{gal}{cycle}\right).$$ [4]

Equations 2 and 3 solve for machine electrical energy and hot water volume consumed per cycle in terms of known values. For Type 3 dishwashers, hot water volume is known to be zero.

Clothes Washers

Estimating the Energy and Water Use of Clothes Washers

Figure 2 shows the flowchart for the solution method used to determine the hot water consumption and machine electrical energy use for clothes washers.

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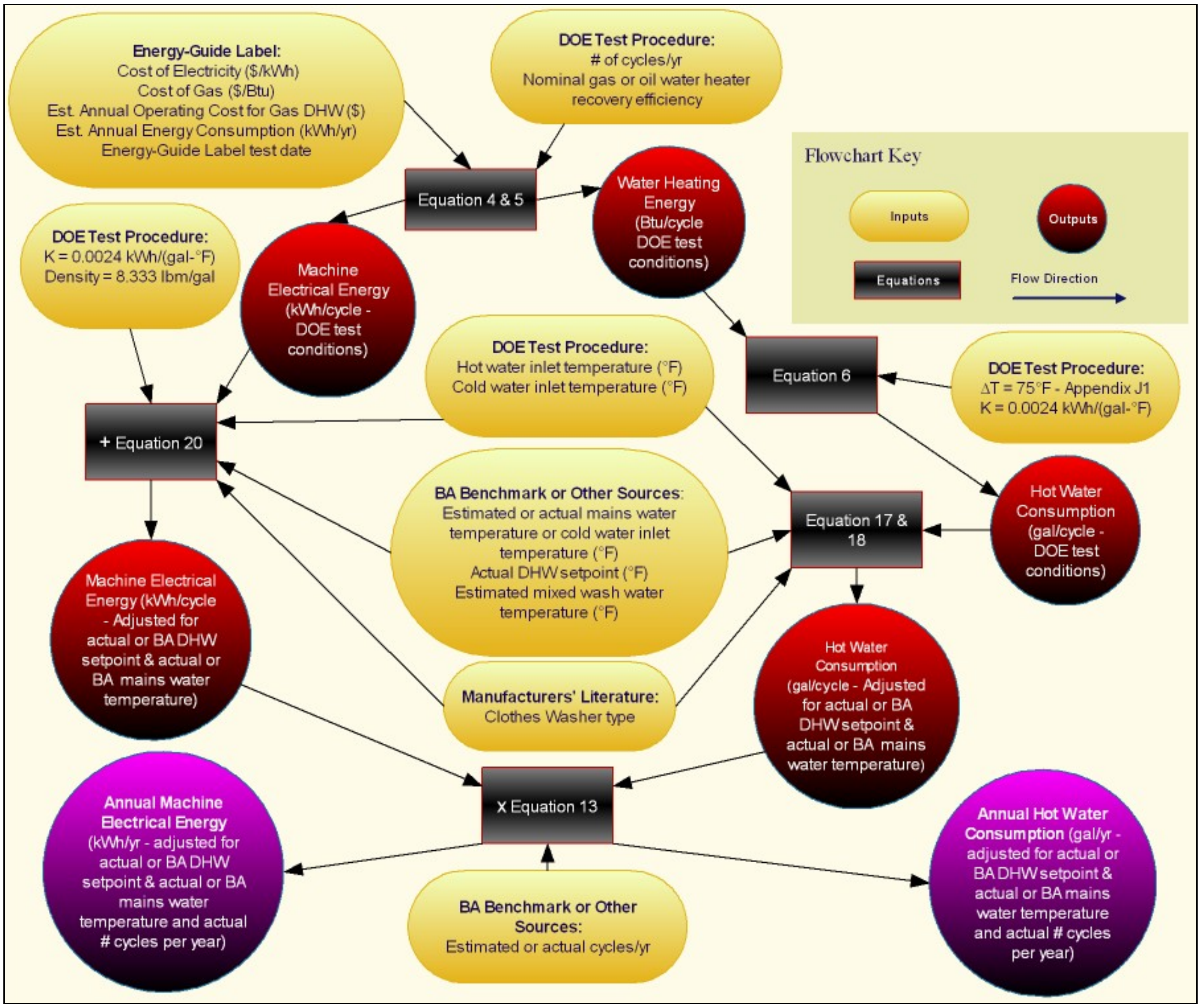
[2] $EAOC_g$ = Estimated Annual Operating Cost for Gas Water Heating ($)
N = Number of Cycles
D_e = Average unit cost of electrical energy ($/kWh)
M = machine energy, M_n or $0.5*(M_n + M_t)$ (kWh/cycle))
D_w = average unit cost in dollars per Btu for gas or oil, as appropriate ($/Btu)
W = Water heating energy, W_n or $0.5*(W_n + W_t)$ (Btu/cycle)

[3] E_{ann} = Annual energy consumption, $N*E_t$ or $N*0.5*(E_n + E_t)$ (kWh)
e = nominal gas or oil water heater recovery efficiency = 0.75

[4] GHW = Gallons of hot water (gal/cycle) for Type 1 dishwashers $\Delta T = 90°F$, for Type 2 dishwashers $\Delta T = 70°F$, K = 0.00240 kWh/(gal-°F)

Figure 2. Solution Method Flowchart for Clothes Washers



Machine Types. To begin solving for the machine electrical energy consumption and hot water volume consumption, it is necessary to understand basic clothes washer types, the following definitions are used here:

- Type 1 clothes washer – does not heat water internally, hot and cold water connections
- Type 2 clothes washer – uses thermostatically controlled water inlet valves to vary the volume of hot and cold water added to the wash load
- Type 3 clothes washer – has an electric element internal to the machine for the purpose of providing auxiliary heating, hot and cold water connections
- Type 4 clothes washer – has an electric element internal to the machine for the purpose of heating all of the water used to wash clothes; cold water connection only.

To estimate the energy consumption of clothes washers, it is necessary to understand energy-use calculations found in 10CFR Part 430, Subpt. B, Appendix J1 (DOE 1999).

Disaggregation of Energy-Guide Label Data. Equations from DOE test procedures that determine estimated operating expenses and estimated annual energy consumption appearing on Energy-Guide labels are as follows:

D) Annual Estimated Energy Cost for Gas Water Heating (for gas and oil heated water):

$$EAOC_g = N * [(D_e * M_{ET}) + (D_w * HE_{TG})]$$ [5]

E) Annual Energy Equation (for gas and oil heated water):

$$E_{ann} = N\left(HE_{TG} * 0.000293 \frac{kWh}{Btu} * e + M_{ET} \right).$$

If (E) is solved for ME_T and is then substituted into (D), the result can be solved for energy required to heat water:

Equation 4: $$HE_{TG} = \frac{EAOC_g - (D_e * E_{ann})}{N\left[D_w - \left(D_e * 0.000293 \frac{kWh}{Btu} * e \right) \right]} \left(\frac{Btu}{cycle} \right).$$

Weighted average machine energy is then given by:

Equation 5: $$M_{ET} = \frac{E_{ann}}{N} - \left(HE_{TG} * 0.00293 \frac{kWh}{Btu} * e \right) \left(\frac{kWh}{cycle} \right).$$

To estimate the hot water volume consumed:

Equation 6: $$GHW_t = \frac{H_{ET}}{K * \Delta T} \left(\frac{gal}{cycle} \right).$$ [6]

Equations 5 and 6 solve for machine electrical energy and hot water volume consumed per cycle in terms of know values. For Type 4 Clothes Washers, hot water volume is known to be zero.

Clothes Dryers

Estimating the Energy Use of Clothes Dryers

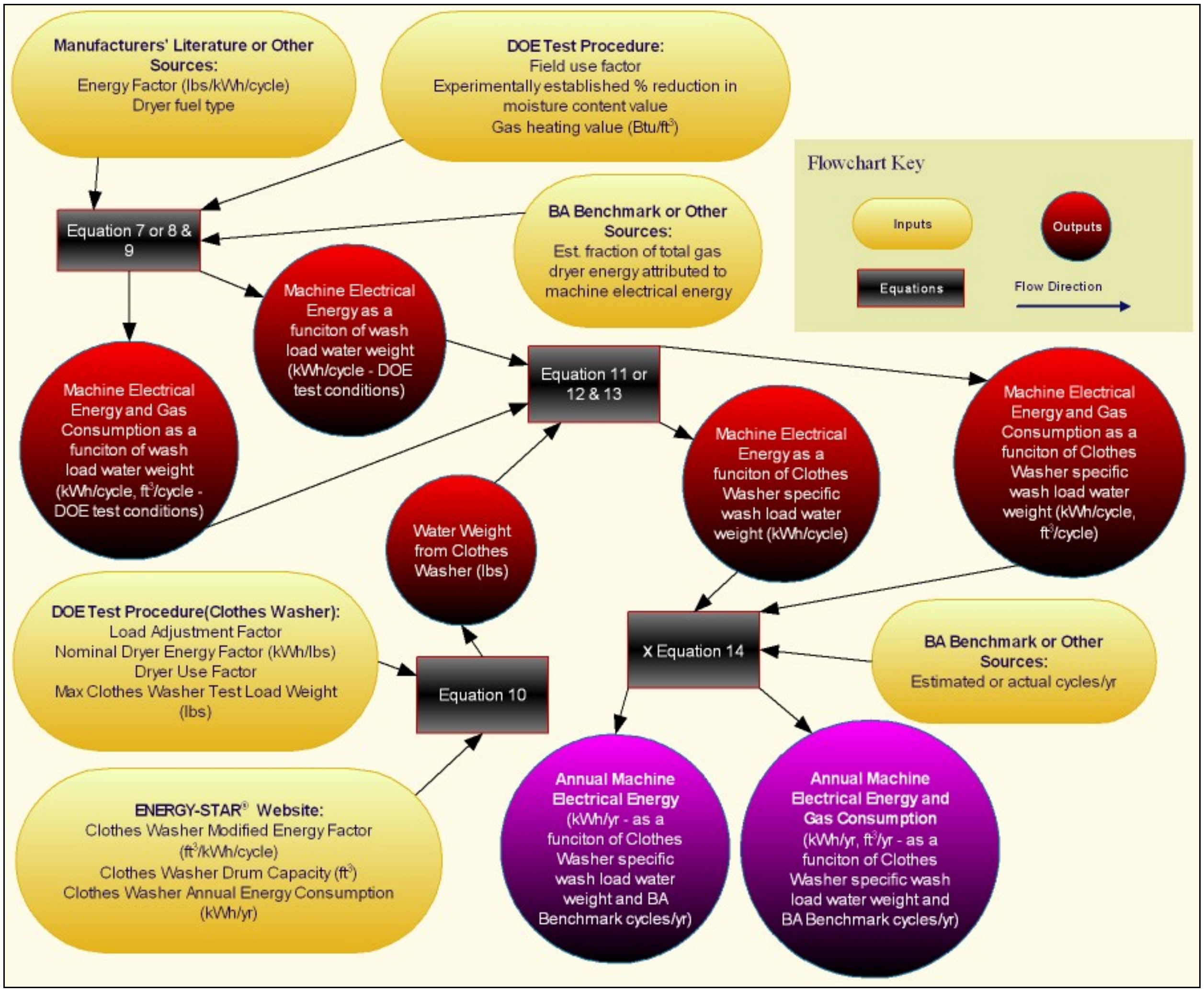
Figure 3 shows the flowchart for the solution method used to determine the machine electrical energy use and gas use for clothes dryers. Energy-Guide labeling is not required for clothes dryers,; however, a DOE test procedure for clothes dryers does exist for the purpose of determining clothes dryer compliance with federal appliance minimum efficiency regulations. In addition, clothes dryer energy use is dependent on moisture content of the wash load. This method incorporates equations used to determine the Modified Energy Factor[7] (MEF) for clothes washers and equations from the DOE test procedure for clothes dryers in order to model any combination of clothes washer and clothes dryer in a coupled fashion.

[5] N = Number of cycles per year assumed (392 cycles/yr)
ME_T = Total weighted per-cycle machine electrical energy consumption (kWh/cycle)
HE_{TG} = HE_T * 1/e * (3412Btu/kWh), gas water-heating energy consumption (Btu/cycle)

[6] GHW_t = weighted average gallons of hot water used under test conditions representative of temperature use factors found in section 5 of Appendix J1 (DOE 1999) (gal/cycle), ΔT = 75°F (Appendix J1)

[7] Modified Energy Factor for clothes washers includes a nominal dryer energy use, which is determined from tests that quantify the amount of water remaining in wash loads as a result of different clothes washer spin cycles.

Figure 3. Solution Method Flowchart for Clothes Dryers



Machine Types. For the purpose of defining clothes dryer machine types, there are two different basic machine types: conventional clothes dryers or heat pump (vapor compression) type clothes dryers that do not vent to the outside. However, the important distinction for dryers is the fuel type (all electric or gas-electric). To estimate the energy consumption of clothes dryers, it is necessary to understand the energy-use calculations in 10CFR Part 430, Subpt. B, App. D (DOE 1999).

Relevant Equations from DOE Test Procedure and Equation Derivation. The two equations of interest are as follows:

F) Clothes dryer efficiency:

$$EF = \frac{TLW_d}{E_{ce}}$$, electric clothes dryers[8]

[8] EF = Energy Factor (lbs-load dry weight/kWh/cycle)
TLW_d = Test load weight for clothes dryer (lbs, dry)
E_{ce} = Total per-cycle electric clothes dryer energy consumption (kWh/cycle)

$$EF = \frac{TLW_d}{E_{cg}}$$, gas clothes dryers [9]

G) Total dryer energy consumption:

$$E_{ce} = E_t * FU * \left(\frac{66}{W_w - W_d} \right)$$, electric clothes dryers [10]

$$E_{cg} = E_{ge} + \left(\frac{E_g}{3412\left(\frac{Btu}{kWh} \right)} \right)$$, gas clothes dryers. [11]

For electric clothes dryers the two equations are solved for E_t:

$$E_t = \frac{\left(\frac{TLW_d}{EF} \right) * (W_w - W_d)}{(FU * 66)}.$$

Because moisture content of the test load is defined as the water weight over the dry-load weight, we can re-write W_w and W_d as follows:

$$W_w = 100\left(\frac{lbs_{water,initial}}{TLW_d} \right) \left(\frac{lbs}{lbs} \right) \text{ expressed as } \%$$ [12]

$$W_d = 100\left(\frac{lbs_{water,final}}{TLW_d} \right)\left(\frac{lbs}{lbs} \right) \text{ expressed as } \%.$$ [13]

Solving these two equations for $W_w – W_d$ and substituting into the equation for E_t:

Equation 7: $$E_t = \frac{100 * \Delta lbs_{water}}{EF * FU * 66} \left(\frac{kWh}{cycle} \right).$$

For gas dryers, we make an assumption about the fraction of total energy for a gas clothes dryer that is attributed to machine electrical energy consumption:

$$E_{ge} = f_l * E_{cg} \,(kWh)$$ [14] and, $$E_g = (1 - f_l) * E_{cg} * 3412\left(\frac{Btu}{kWh} \right).$$

Solving the gas dryer equations for E_{te} and E_{tg}:

Equation 8: $$E_{te} = \frac{f_l * 100 * \Delta lbs_{water}}{EF * FU * 66} \left(\frac{kWh}{cycle} \right)$$

Equation 9: $$E_{tg} = \frac{(1 - f_l) * 100 * \Delta lbs_{water} * 3412\left(\frac{Btu}{kWh} \right)}{EF * FU * 66 * GEF} \left(\frac{ft^3}{cycle} \right).$$

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9 E_{cg} = Total per-cycle gas clothes dryer energy consumption (kWh/cycle)

10 E_t = Measured clothes dryer electrical energy consumption during test cycle (kWh)

FU = Field use factor, 1.18 for time termination control system and 1.04 for automatic control systems.

66 = experimentally established value for the percent reduction in the moisture content of the test load (%, DOE 1999)

W_w = Moisture content of the wet test load ($lbs_{water}/lbs_{dry\ cloth}$)

W_d = Moisture content of the test load after drying ($lbs_{water}/lbs_{dry\ cloth}$)

11 $E_{ge} = E_{te} * FU * (66/(W_w – W_d))$, per-cycle gas clothes dryer electrical energy consumption (kWh/cycle)

$E_g = E_{tg} * FU * GEF * (66/(W_w – W_d))$, per-cycle gas clothes dryer gas energy consumption (Btu/cycle)

12 $lbs_{water,initial}$ = water weight before drying (lbs)

13 $lbs_{water,final}$ = water weight after drying (lbs)

14 f_l = fraction of total gas clothes dryer energy attributed to machine electrical energy

Equations 7, 8, and 9 solve for measured dryer energy consumption in terms of the change in weight of water during the drying cycle. We make the simplifying assumption that all of the water weight remaining in a load of wash after the clothes-washer final spin cycle is removed during the drying cycle. The water weight in a load of clothes can be calculated and substituted into equations 7, 8, and 9 to calculate the energy use of the clothes dryer as a function of the water weight remaining in the wash load. The water weight remaining in a wash load after the final clothes washer spin cycle can be estimated if the following values are known:

- Clothes washer modified energy factor (MEF, ft^3/kWh)
- Clothes washer drum capacity (ft^3)
- Weight of water transferred from clothes washer to clothes dryer (lbs).

The three equations of interest are as follows:

H) $MEF = \frac{C}{E_{TE} + D_E}$ [15]

I) $RMC = \frac{D_E}{LAF * DEF * DUF * TLW_w} + 4\%$ (%)[16]

J) $\text{Water weight} = RMC * TLW_w$.

Using substitution we have:

Equation 10: $$\text{Water weight} = \left[\frac{\left(\frac{C}{MEF}\right) - E_{TE}}{\left(LAF * DEF * DUF * TLW_w\right)} + 0.04 \right] * TLW_w .$$

Substituting equation 10 into equations 7, 8, and 9 for the clothes dryer:

Equation 11: $$E_{t,new} = \frac{100\left\{\left[\frac{\left(\frac{C}{MEF_{washer}}\right) - E_{TE}}{LAF * DEF * DUF * TLW_w} + 0.04\right] * TLW_w\right\}}{EF_{dryer} * FU * 66}\left(\frac{kWh}{cycle}\right)$$, electric dryer

Equation 12: $$E_{te,new} = \frac{f_1 * 100\left\{\left[\frac{\left(\frac{C}{MEF_{washer}}\right) - E_{TE}}{LAF * DEF * DUF * TLW_w} + 0.04\right] * TLW_w\right\}}{EF_{dryer} * FU * 66}\left(\frac{kWh}{cycle}\right)$$, electrical energy consumed by a gas clothes dryer

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[15] MEF = Modified Energy Factor (ft^3/kWh/cycle)
C = W/d, Capacity (ft^3), W = Weight of water (lbs), d = Density of water (62.0 lbs/ft^3 for 100 °F or 62.3 lbs/ft^3 for 60 °F)
$E_{TE} = M_E + HE_T$, Total per-cycle energy consumption when electrically heated water is used (kWh/cycle)
D_E = Nominal dryer energy consumption for removal of remaining moisture content (kWh/cycle)

[16] LAF = 0.52, load adjustment factor
TLW_w = Max value as shown in test load table, 10CFR Part 430, Subpt. B, App. J1, Table 5.1 (lbs/cycle)
RMC = Remaining moisture content ($lbs_{water}/lbs_{drycloth}$, expressed as %)
DEF = 0.5 (kWh/lb), nominal energy factor for clothes dryer
DUF = 0.84, clothes dryer use factorRMC = $lbs_{water}/lbs_{drycloth}$ (expressed as %)

Equation 13: $$E_{tg,new} = \frac{(1-f_1)*100\left\{\left[\frac{\left(\frac{C}{MEF_{washer}}\right) - E_{TE}}{LAF*DEF*DUF*TLW_w} + 0.04\right]*TLW_w\right\}}{EF_{dryer}*FU*66*GEF}\left(\frac{ft^3}{cycle}\right)$$, gas consumption of the dryer.

Equations 11, 12, and 13 solve for clothes-dryer energy use that is representative of the remaining water weight in the wash load as a result of the final clothes-washer spin cycle. This method assumes a linear relationship between water weight and the clothes dryer energy consumption based on data for a conventional clothes dryer tested by the National Institute of Standards and Technology (Kao 1998).

Building America Application

Building America Benchmark and Prototype

The Benchmark represents a hypothetical residential building that varies its physical and energy-related features according to climate and prototype house design with the intent of representing typical 1990s construction. For appliances the Benchmark specifies daily hot water consumption, annual electrical and gas consumption, hourly usage patterns, DHW tank setpoint, and monthly incoming water-mains temperatures with the intent of modeling a whole building with an hourly annual building energy-simulation tool. The Benchmark assumes a 3-ft^3 clothes washer capacity, which corresponds to a 12.5-lb test load weight, and an 8-place-setting capacity dishwasher. The prototype home must be modeled using the same assumption for DHW tank setpoint and mains-water temperatures. The assumed number of cycles for the prototype appliances are defined in the Building America Performance Analysis Procedures (Hendron et al. 2004). The equations below specify appliance cycles per year as a function of number of bedrooms for the prototype:

Equation 14: $$N_{proto\,CW} = 392*\left[½+\left(\frac{N_{br}}{6}\right)\right]*\left(\frac{12.5lbs}{TLW_{proto}(lbs)}\right)\left(\frac{cycles}{yr}\right)$$ **[17]**

Equation 15: $$N_{proto\,CD} = N_{proto\,CW}*DUF\left(\frac{cycles}{yr}\right)$$ **[18]**

Equation 16: $$N_{proto\,DW} = 215*\left[½+\left(\frac{N_{br}}{6}\right)\right]*\frac{8}{\text{actual place setting capacity}}\left(\frac{cycles}{yr}\right).$$ **[19]**

For each of the appliances, the prototype cycles per year is multiplied by the adjusted machine electrical energy consumption and adjusted hot water volume consumed to give new annual totals. Outside of Building America, other users may wish to use different assumptions for the number of cycles per year that each appliance experiences.

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[17] $N_{proto\,CW}$ = Prototype clothes washer annual operation frequency (cycles/yr)
N_{br} = # of Bedrooms
TLW_{proto} = prototype clothes washer test load weight, determined using Table 5.1 Appendix J1 (DOE 1999)
[18] $N_{proto\,CD}$ = Prototype clothes dryer annual operation frequency (cycles/yr)
DUF = 0.84, from DOE test procedures
[19] $N_{proto\,DW}$ = Prototype dishwasher cycles per year (cycles/yr)

Effect of Mains Water Temperature and Hot Water Temperature

The energy consumption of most dishwashers and clothes washers is affected by the mains or cold water inlet temperature and the domestic hot water temperature. The exception is Type 1 dishwashers and clothes washers, for which the energy consumption and hot water consumption of the machine will not vary from the measured values under DOE test conditions as a result of the lack of built in controls and assuming "generic" user behavior for comparison purposes.

Thermostatic Control Valves. Type 2 clothes washers vary the amount of hot water the machine uses in order to attain a specific wash temperature by opening and closing hot and cold water valves during the fill portion of the cycle that utilizes both hot and cold water. We make the assumption that the mixed water temperature in a Type 2 clothes washer during cycles that draw hot and cold water is 92.5°F based a field test Colorado. In order to correct the hot and cold water volumes for this control type, a general derivation of the correction in hot water volume for a Type 2 clothes washer operating with water temperatures that differ from the test conditions is shown below. During machine sub cycles that use both hot and cold water the volume fraction of hot water is defined as follows:

$X = \frac{GHW_t}{GWT}$,[20] where $GWT = GHW_t + GCW_t$.[21]

These equations are solved for GCW_t and substituted into conservation of energy:

$T_{HWI} * GHW_t + T_{CWI} * GCW_t = T_{mixed} * GWT$.[22]

Then solved for volume fraction to give:

Equation 17: $X = \frac{T_{mixed} - T_{CWI}}{T_{HWI} - T_{CWI}}$.

The volume fraction of hot water is defined by the test condition temperatures and an assumed mixed temperature. In order to calculate the hot water used under actual conditions where the hot and cold water temperatures are different from the test conditions the conservation of energy equation is as follows:

$T_{hot,act}\left(GHWt + \Delta V\right) + T_{cold,act}\left(GCW_t - \Delta V\right) = T_{mixed} * GWT$.[23]

Substituting GCW_t and GWT terms and solving for ΔV:

Equation 18: $\Delta V = GHW_t \left(\frac{\frac{1}{X}\left(T_{mixed} - T_{cold,act}\right) + \left(T_{cold,act} - T_{hot,act}\right)}{T_{hot,act} - T_{cold,act}} \right)$.

[20] GHW_t = Volume of hot water used under test conditions(gal)
GWT = Volume of water used during subcycles that using hot and cold water under test conditions (gal)
X = Hot water volume fraction for machine subcycles that use hot and cold water (assumed 92.5ºF mixed wash water temperature)
[21] GCW_t = Volume of cold water used during subcycles using hot and cold water under test conditions (gal)
[22] T_{mixed} = Mixed water temperature, current assumption is 92.5°F for Type 2 machines
T_{HWI} = Hot water inlet temperature, 135°F for J1 test conditions
T_{CWI} = Cold water inlet temperature, 60°F for J1 test conditions
[23] $T_{hot, act}$ = new hot water temperature, if different from test conditions (°F)
$T_{cold, act}$ = new cold water temperature, if different from test conditions (°F)
ΔV = increase in hot water volume and decrease in cold water volume (gal)

ΔV is known for any combination of hot and cold water inlet temperatures, and the quantity of hot water used by the clothes washer can be estimated under alternate conditions.

Internal Electric Water Heaters. Type 2 and 3 dishwashers, as well as Type 3 and 4 clothes washers, have internal electric water-heating elements that adjust the water temperature. The general solution for each of these machines that will correct the machine electrical energy for alternate conditions is as follows:

Equation 19: $Q = m * K * (T_{final} - T_{initial})$. [24]

For dishwashers: $m = d * GHW_t \; (lbm)$. [25]

For clothes washers: $m = d * \frac{GHW_T}{X} \; (lbm)$.

For Type 3 clothes washers: $T_{final} = X * T_{HWI} + (1 - X) * T_{CWI}$ [26]

$T_{initial} = X * T_{hot,act} + (1 - X) * T_{cold,act}$. [27]

Substituting $T_{initial}$ and T_{final} into $Q = m * C_p * (T_{final} - T_{initial})$ with simplifications gives us,

Equation 20: $Q = m * K * \lfloor X(T_{HWI} - T_{CWI} - T_{hot,act} + T_{cold,act}) + T_{CWI} - T_{cold,act} \rfloor$.

Additional machine electrical energy for Type 3 clothes washers (supplemental internal electric heating element) for conditions that differ from the test procedure is heavily dependent on how the Type 3 clothes washer mixes hot and cold water (we assume that a 0.5 fixed-volume fraction is reasonable for calculation of $T_{initial}$ and T_{final}).

Additional machine electrical energy for Type 4 clothes washers (cold water inlet only) is calculated by setting T_{final} to be 60°F and $T_{initial}$ is set to the cold water inlet temperature.

Conclusion

Using information available on Energy-Guide labels, the ENERGY-STAR website,[28] California Energy Commission's Appliance website,[29] and manufacturer's literature for dishwashers, clothes washers, and clothes dryers, the residential energy analyst will be able to generate inputs to whole building energy simulation tools that are specific to real appliance models. This methodology allows the analyst to do the following:

- Disaggregate machine electrical energy and hot water consumption for a particular dishwasher or clothes washer model under DOE test conditions for basic appliance control strategies

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[24] Q = energy necessary to heat water (kWh)
m = mass of water (lbm)
T_{final} = final water temp = 140°F for Type 2 Dishwashers; = 50°F for Type 3 Dishwashers; = 60°F for Type 4 Clothes Washers (°F)
$T_{initial}$ = initial water temperature, $T_{initial}$ = hot water inlet temp for Type 2 Dishwashers; = cold water inlet temp for Type 3 Dishwashers and Type 4 Clothes Washers (°F)

[25] d = density (8.333lbm/gal)

[26] T_{HWI} = 135°F for Appendix J1
T_{CWI} = 60°F for Appendix J1

[27] $T_{hot,\,act}$ = prototype domestic hot water temperature, 120°F in the Building America context
$T_{cold,\,act}$ = prototype cold water inlet temperature, monthly mains water temperature for Building America

[28] www.energystar.gov/ia/products/prod_lists/ appliances_prod_list.xls

[29] www.energy.ca.gov/appliances/appliance/ excel_based_files/cook_wash/

- Account for variability in incoming water temperatures that may affect the energy and water use of dishwashers and clothes washers
- Model the interaction of clothes washers and clothes dryers for any combination of these appliances
- Account for a varying number of cycles per year that the appliance is used
- Compare appliance models in greater detail than comparing energy and cost information presented on Energy-Guide labels or the Energy-Star website.

The methodology does not account for occupant behavior, such as occupants who use only cold water only for clothes washing, hot water distribution system losses, dryer energy needed to heat a load of clothes to the point where moisture in the wash load begins to evaporate or a clothes dryer that is undersized relative to the clothes washer drum capacity. To assist residential energy efficiency research, NREL has the following spreadsheet tool to perform these calculations assuming Benchmark operating conditions (www.eere.energy.gov/buildings/building_america/pa_resources.html).

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14. ABSTRACT *(Maximum 200 Words)*
Building America teams are 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, clothes dryer, refrigerator, and range), and miscellaneous electric 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 (as much as 50% for very efficient homes) as energy efficient homes have become more commonplace through programs such as ENERGY STAR and Building America. As modern appliances become more sophisticated the residential energy analyst is faced with a daunting task in trying to calculate the energy savings of high efficiency appliances. Unfortunately, most whole-building simulation tools do not allow the input of detailed appliance specifications. Using DOE test procedures the method outlined in this paper presents a reasonable way to generate inputs for whole-building energy-simulation tools. The information necessary to generate these inputs is available on Energy-Guide labels, the ENERGY-STAR website, California Energy Commission's Appliance website and manufacturer's literature. Building America has developed a standard method for analyzing the effect of high efficiency appliances on whole-building energy consumption when compared to the Building America's Research Benchmark building.

15. SUBJECT TERMS
Building America; U.S. Department of Energy; energy efficient homes; miscellaneous electrical loads; MELs; appliances; DOE test procedures

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