Development of an Energy-Savings Calculation Methodology for Residential Miscellaneous Electric Loads

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ABSTRACT

To meet whole-house energy savings targets beyond 50% in residential buildings, new technologies and systems approaches must be developed to address miscellaneous electric loads (MELs). MELs are the small and diverse collection of energy-consuming devices found in homes, including what are commonly known as plug loads (televisions, stereos, microwaves), along with all hard-wired loads (doorbells, security systems, garage door openers) that do not fit into other major end-use categories (space conditioning, domestic hot water, ventilation, major appliances, and lighting). MELs present special challenges because their purchase and operation are largely under the control of the occupants. If no steps are taken to address MELs, they can constitute 40%-50% of the remaining source energy use in homes that achieve 60-70% whole-house energy savings, and this percentage is likely to increase in the future as home electronics become even more sophisticated and their use becomes more widespread. Building America (BA), a U.S. Department of Energy research program that targets 50% energy savings in new homes by 2015 and 100% savings (zero net energy) by 2020, has begun to identify and develop advanced solutions that can significantly reduce MELs.

As part of the ongoing efforts by Building America to create a consistent set of guidelines for the analysis of whole-house energy use, the National Renewable Energy Laboratory (NREL) has disaggregated the MEL end-use category and developed a methodology to calculate energy savings for measures that have the potential to reduce these loads. This disaggregation includes electricity use for more than 100 individual MELs, active vs. low-power draw, hours in each operating mode, market penetration, correlation with house size and occupancy, and impacts on latent and sensible heat loads. The MEL Analysis Spreadsheet posted on the BA website (www.eere.energy.gov/buildings/building_america/pa_resources.html) documents this disaggregation and provides the framework for calculating energy savings for prototype houses with specific MEL improvements.

Introduction

Miscellaneous electric loads are composed of the diverse assortment of products, devices, and electrical equipment found in some combination in every household. MELs are usually either small end-uses found in a large percentage of homes (such as toasters, televisions, and coffee makers) or large end-uses that are only found in a small fraction of homes (such as well pumps, waterbed heaters, and aquariums). This variety makes it very difficult to find systems-based solutions that can have a significant impact on the total energy use of MELs in a typical home, especially when one takes into account the role of the occupants in choosing and operating these devices.

Despite the challenges associated with reducing MELs, they represent a growing fraction of whole-house energy use in high-performance homes and, therefore, we must be careful not to overlook them. As an example, consider the McStain Discovery House in Colorado, which

successfully achieved 54% whole-house energy savings compared to the Building America Research Benchmark (Hendron 2005). As shown in Figure 1, the fraction of total source energy use associated with MELs increased from 14% to 32%, while significant energy savings were achieved in the other end-use categories (space heating, space cooling, domestic hot water [DHW], lighting, and major appliances). It was necessary to reduce non-MEL energy use by 65% in order to reach 54% whole-house savings, because no practical reduction in MELs could be attained for the Discovery House. Unless this load can be reduced in the future, large photovoltaic systems or other forms of site electricity generation will be the only alternative to achieve net zero energy homes.

Figure 1. MELs Are Becoming a Much More Important End-Use in Energy-Efficient Homes Like the Discovery House in Loveland, Colorado
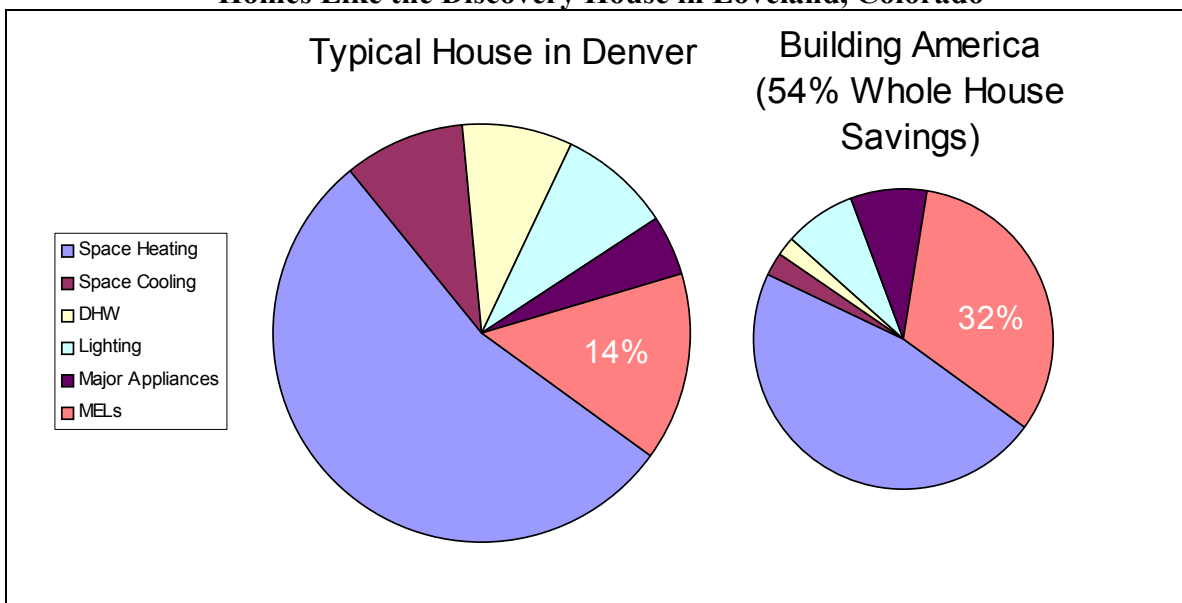
NREL and other research organizations have completed some important preliminary studies to characterize the magnitude and nature of the most common MELs and to identify promising alternative technologies and methodologies to reduce these loads (Wenzel et al. 1997; Zogg & Alberino 1998; A.D. Little 1999; Rosen & Meier 1999a; Rosen & Meier 1999b; Ross & Meier 2000; Meier 2002, Nordman 2004). Lawrence Berkeley National Laboratory (LBNL) has conducted research on energy savings opportunities for several specific product types, especially in the categories of consumer electronics and home-office equipment. They have also done extensive work to quantify typical end-use loads for small appliances and plug loads and have conducted studies of standby losses and low-power modes in residential buildings as part of their efforts in support of ENERGY STAR and the California Energy Commission (CEC). The ENERGY STAR program is making important strides toward establishing criteria for many energy-efficient products, but these only scratch the surface of the total energy consumption associated with MELs, and these products are usually purchased at the discretion of the occupants. Comprehensive, systems-based approaches involving the builder and architect are necessary to ensure some degree of energy savings regardless of occupant purchasing decisions and usage patterns.

A consistent approach for calculating annual energy savings, including systems interactions caused by sensible and latent loads, has been a missing component of MEL research in the past. Such an approach is essential if programs like BA are to achieve significant defensible savings in the MEL end-use category. To this end, NREL developed an MEL Analysis Spreadsheet in consultation with the BA industry team analysts. This spreadsheet is now available as an optional method for analyzing MEL, and is posted on the BA website (http://www.eere.energy.gov/buildings/building_america/docs/bench_mels_012406.xls).

Methodology Development

Past Treatment of MELs in the Benchmark

The 2005 Building America Benchmark (Hendron 2005) and the Building America Performance Analysis Procedures (Hendron et al. 2004) form the framework for calculating whole-house source energy savings for Building America prototype houses. However, until 2006, MELs have been treated in a fairly simplistic way, and no standard methodology existed to allow the analyst to calculate energy savings for MEL improvements. Site electricity use associated with MELs was defined as a simple function of finished floor area for both the Benchmark and the prototype using Equation 1. A multiplier was applied if the prototype was located in one of the four most populated states as defined in the 2001 Energy Information Administration (EIA) Residential Energy Consumption Survey (RECS) (EIA 2001).[1] This multiplier was important because the magnitude of the electricity use for MELs in a particular state could have a significant effect on the size of the photovoltaic system necessary to achieve net zero energy. A multiplier of 1.0 was used for all states not listed in Table 1 because insufficient information was available about the magnitude of MELs in those states. The derivation of state multipliers will be described in more detail later in this paper.

$$E_{MEL} = 1.67 \text{ x FFA x } F_S \tag{1}$$

where

E_{MEL} = site electricity for MELs in the 2005 Benchmark (kWh/yr)
FFA = finished floor area, including finished basements (ft^2)
F_S = state multiplier from Table 1.

Table 1. MEL Multipliers (F_S) for Four Most Populous States

State	Multiplier (F_S)
New York	0.82
California	0.77
Florida	0.94
Texas	1.11
All other States and territories	1.00

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[1] It is important to note that the RECS analysis process uses a nonlinear regression technique to quantify each end-use, including MELs. Because of potential interactions between independent variables, for example between MELs and cooling energy, it is possible that systematic errors in the regression analysis can result in overestimation or underestimation of the MELs in a particular state. RECS also includes an independent variable driven by the number of household members and their ages. This catch-all variable represents electricity consuming products that cannot be quantified individually and equals about 48% of total MEL energy. Our assumption is that this variable includes only MELs, but it may also include errors in the estimation of other end-uses.

The MEL equation used in the Benchmark was developed for maximum consistency with the corresponding energy consumption in single-family homes according to the 2001 RECS, along with several other references (PG&E 1997; Wenzel et al. 1997; KEMA 2004). In Figure 2, these references are compared to the MEL equation for California.

Figure 2. 2005 Benchmark MELs for a Three-Bedroom House in California Compared to Other References
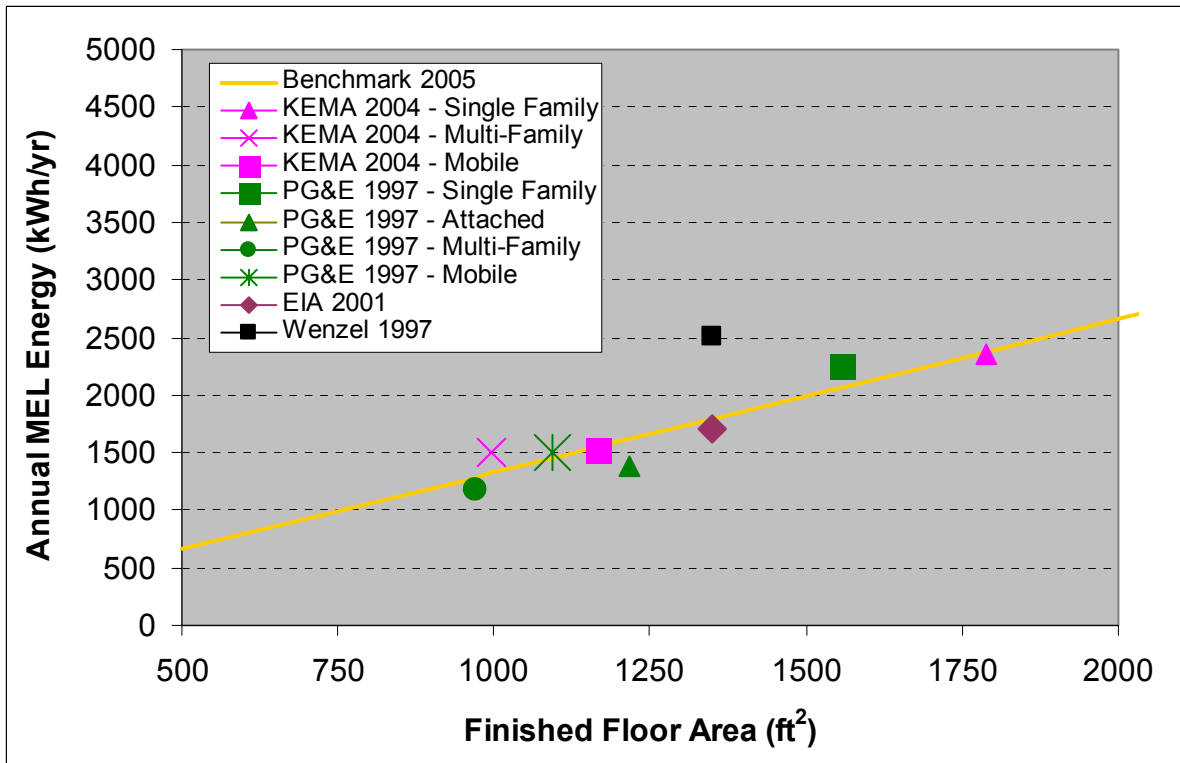
Disaggregation of MEL End-Uses

NREL and the BA teams decided to add more realism and accuracy to the analysis of MELs beginning in 2006. The first step necessary in the development of an MEL analysis methodology was to separate the MEL end-use category into individual products and equipment. This disaggregation has been performed in various configurations by several researchers in the past (EIA 1993; Krigger & Dorsi 1994; EIA 1999; PG&E 1997; Sanchez & Meier 1997; Wenzel et al. 1997; Thorne & Suozzo 1998; Rosen & Meier 1999a; Rosen & Meier 1999b; CREEDAC 2001; EIA 2001; Pinckard et al. 2003; KEMA 2004; Nordman 2004). NREL decided to take maximum advantage of these previous studies in the development of an MEL breakdown for use with the Benchmark. The study by Wenzel was the primary reference for values of Unit Energy Consumption (UEC), and the RECS studies from 2001, 1997, and 1993 (EIA 2001, 1999, 1993) were the principal sources of data on market penetration. Other studies were used to fill in the gaps, and more recent data took precedence over older and possibly out-dated information. Finally, an "Other" category was added to force the total built-up MEL energy use to match the current 2005 Benchmark MEL energy use for an average size 1920-ft^2, three-bedroom house. The "Other" MEL category only constitutes 9.5 kWh/yr, or less that half of one percent of the

total MEL end-use, which is a good indication that our disaggregated MELs are fairly comprehensive and realistic.

The resulting breakdown of 119 individual MELs is summarized in Table 2 for a typical 1920-ft^2, three-bedroom house. The categorization of loads is largely based on the taxonomoy developed by LBNL (Nordman and McWhinney 2006), with a few minor adaptations to meet the needs of BA. For programs like BA that focus on new residential construction, the highest priority items in the MEL category are likely to be those where the builder has some degree of control, such as hard-wired loads (certain standby losses, garbage disposals, doorbells, ceiling fans) and certain large appliances that could potentially be provided with a new house (freezers, second refrigerators, microwaves). An effort was made to capture the collection of MELs that were most common in the late 1990s time frame for consistency with the theoretical vintage of the Benchmark. The mix of MELs and associated energy consumption will evolve over time as new products enter the market and old ones become obsolete.
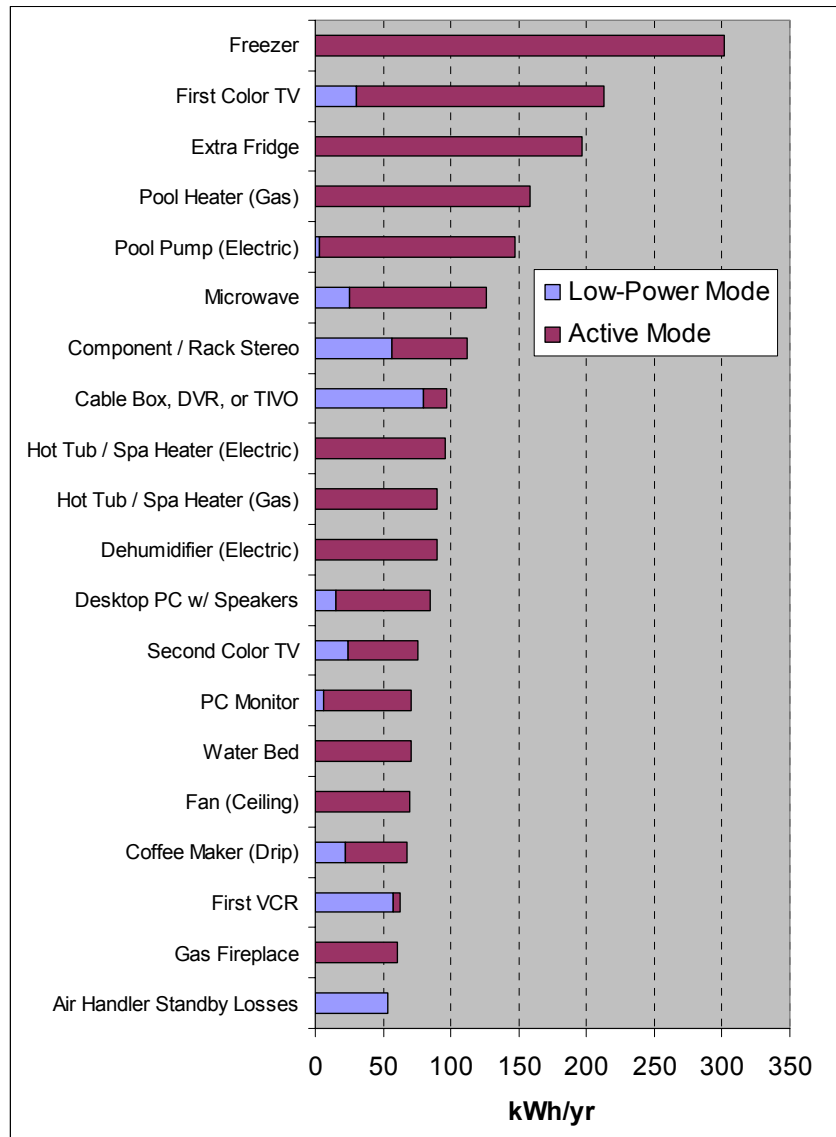
Standby Versus Active Power

Electricity use for most MELs can occur at several different power levels. The three most common power levels are "active", "ready", and "standby". Active mode occurs while the product is being used for its primary purpose. Ready status occurs while a product is turned on, but is not in use. Standby is defined as the lowest energy state of a product while remaining connected to a power supply (IEC 2005). For the sake of simplicity, we grouped "standby" and "ready" together as "low-power modes". An MEL may also have other intermediate states (such as "idle" or "sleep") that we have also included in the "low-power" category. If the lowest power level is the same as the active state for a certain product (a freezer, for example), then we don't view the product as having any low-power modes.

A number of previous studies were of great value as we tried to quantify typical power consumption rates for each MEL in each mode of operation (Huber 1997; Thorne & Suozzo 1998; Zogg & Alberino 1998; Rosen & Meier 1999a; Rosen & Meier 1999b; CREEDAC 2001; Roberson et al. 2002; Nordman 2004; Rainer et al. 2004). A few gaps were filled in by back-calculating the power levels necessary to produce the known average UEC (from Table 2) based on an estimated number of operating hours in each mode. Figure 3 shows the average household energy use for a few of the high-impact MELs in the Benchmark, along with the fractions attributable to low-power vs. active mode. It is noteworthy that many MELs are dominated by energy in low-power mode, and many consume electricity only in active mode. Our estimate of the overall fraction of MEL energy associated with low-power modes is approximately 24% for the Benchmark.

Table 2. Default Miscellaneous Electric Loads for a 1920-ft^2, Three-Bedroom House

Miscellaneous Electric Load	Avg Units/ Hshld	Energy/ Unit kWh/yr	Energy/ Hshld kWh/yr	Miscellaneous Electric Load	Avg Units/ Hshld	Energy/ Unit kWh/yr	Energy/ Hshld kWh/yr
Electronics				*Infrastructure*			
Answering Machine	0.650	33.5	21.8	Baby Monitor	0.100	22.8	2.3
Boombox / Portable Stereo	0.670	16.8	11.3	Carbon Monoxide Detector	0.260	17.5	4.6
Cable Box	0.637	152.7	97.3	Doorbell	0.670	44.0	29.5
Cell Phone Charger	0.450	77.4	34.8	Garage Door Opener	0.266	35.0	9.3
Color TV (Fifth or More)	0.028	45.8	1.3	Ground Fault Circuit Interrupter (GFCI)	3.850	6.2	23.9
Color TV (First)	0.986	215.5	212.5	Smoke Detectors	0.840	3.5	2.9
Color TV (Fourth)	0.104	52.1	5.4	Sump Pump	0.099	40.0	3.9
Color TV (Second)	0.669	112.7	75.4	*Personal Care*			
Color TV (Third)	0.296	66.7	19.7	Curling Iron	0.532	1.0	0.5
Compact Stereo	0.460	112.3	51.6	Electric Shaver	0.470	12.8	6.0
Component / Rack Stereo	0.730	153.0	111.7	Electric Toothbrush Charger	0.118	19.3	2.3
Copy Machine	0.020	25.0	0.5	Hair Dryer	0.837	0.6	0.5
Cordless Phone	0.601	23.2	13.9	Heat Lamp	0.010	13.0	0.1
Desktop PC w/ Speakers	0.592	143.9	85.2	*HVAC*			
Dot Matrix Printer	0.030	115.0	3.5	Air Cleaner	0.217	65.7	14.2
DSL/Cable Modem	0.200	17.6	3.5	Air Handler Standby Losses	0.800	67.2	53.8
DVD Player	0.472	50.1	23.7	Fan (Ceiling)	1.400	50.0	70.0
Equalizer	0.049	14.7	0.7	Fan (Portable)	0.946	11.3	10.7
Fax Machine	0.030	326.3	9.8	Humidifier	0.150	100.0	15.0
Home Security System	0.187	195.1	36.5	HVAC Controls	1.000	20.3	20.3
Laptop PC (Plugged In)	0.152	47.0	7.1	*Other*			
PC Monitor	0.592	119.8	70.9	Auto Block Heater	0.019	250.0	4.8
Power Speakers	0.296	24.4	7.2	Battery Charger	0.437	14.8	6.5
Printer (Inkjet)	0.118	39.0	4.6	Extra Refrigerator	0.179	1100.0	196.9
Printer (Laser)	0.049	92.5	4.5	Freezer	0.323	935.0	302.0
Radio	0.493	9.1	4.5	Garbage Disposal	0.404	10.0	4.0
Satellite Dish Box	0.202	131.7	26.6	Heat Tape	0.030	100.0	3.0
Scanner	0.050	49.0	2.4	Instant Hot Water Dispenser	0.006	160.0	1.0
Subwoofer	0.099	68.3	6.7	Kiln	0.020	50.0	1.0
VCR (First)	0.876	71.3	62.5	Large Marine Aquarium (40-60 gal)	0.002	740.0	1.8
VCR (Second)	0.320	68.9	22.1	Lawn Mower (Electric)	0.059	42.9	2.5
VCR (Third or More)	0.072	68.6	4.9	Lg Freshwater Aquarium (40-60 gal)	0.024	340.0	8.1
Video Gaming System	0.631	20.4	12.9	Md Freshwater Aquarium (20-40 gal)	0.024	180.0	4.3
Housewares				Medium Marine Aquarium (20-40 gal)	0.002	615.0	1.5
Blender	0.788	7.0	5.5	Pipe and Gutter Heaters	0.010	53.0	0.5
Bottled Water	0.010	300.0	3.0	Shop Tools	0.130	26.4	3.4
Broiler	0.010	80.0	0.8	Sm Freshwater Aquarium (5-20 gal)	0.024	105.0	2.5
Can Opener	0.650	3.0	2.0	Small Marine Aquarium (5-20 gal)	0.002	245.0	0.6
Clock	0.956	26.0	24.8	Surge Protector / Power Strip	0.360	3.9	1.4
Clock Radio	1.260	14.9	18.8	Timer (Irrigation)	0.050	45.2	2.3
Coffee Maker (Drip)	0.685	99.3	68.0	Timer (Lighting)	0.280	20.1	5.6
Coffee Maker (Percolator)	0.167	65.0	10.9	Trash Compactor	0.010	50.0	0.5
Deep Fryer	0.148	20.0	3.0	Water Bed	0.066	1068.0	70.5
Electric Blanket	0.286	120.0	34.3	*Fixed MELs*			
Electric Griddle	0.256	6.0	1.5	Coral Reef Aquarium (Electric)	0.001	4500.0	3.6
Electric Grill	0.010	180.0	1.8	Dehumidifier (Electric)	0.092	972.4	89.5
Electric Knife	0.374	1.0	0.4	Gas Fireplace	0.035	1760.0	60.9
Espresso Machine	0.069	19.0	1.3	Gas Grill	0.029	879.0	25.5
Food Slicer	0.414	1.0	0.4	Gas Lighting	0.005	557.0	2.9
Hand Mixer	0.877	2.0	1.8	Hot Tub / Spa Heater (Electric)	0.056	1704.0	95.4
Heating Pads	0.670	3.0	2.0	Hot Tub / Spa Heater (Gas)	0.038	2374.0	90.2
Hot Plate	0.236	30.0	7.1	Hot Tub / Spa Pump (Electric)	0.094	460.0	43.2
Iron	0.847	53.0	44.9	Other	1.000	9.5	9.5
Microwave	0.933	135.1	126.1	Pool Heater (Electric)	0.004	2300.0	9.2
Popcorn Popper	0.305	5.0	1.5	Pool Heater (Gas)	0.024	6506.0	158.7
Slow Cooker / Crock Pot	0.581	16.0	9.3	Pool Pump (Electric)	0.066	2228.3	147.1
Toaster	0.837	43.7	36.6	Well Pump (Electric)	0.129	400.0	51.6
Toaster Oven	0.345	50.0	17.3	*Totals*			
Vacuum Cleaner (Cordless)	0.207	36.5	7.6	*Total Electronics*			*1057*
Vacuum Cleaner (Upright)	0.946	31.0	29.3	*Total Housewares and Other MELs*			*2149*
Waffle Iron	0.325	25.0	8.1	*Total MELs*			*3206*

Figure 3. Low-Power and Active Energy per Household for the 20 Most Important MELs

Hours Per Day in Each Operating Mode

Daily operating hours for each MEL, including average hours per day where the MEL is disconnected from any power supply, were estimated using most of the same references that were used to determine typical power levels in each mode of operation. However, much less information was available on this topic. Ultimately, about two-thirds of the values for hours per day in each mode were either derived based on known values of annual energy use and power consumption, or estimated based on the personal experience of the authors.

The MEL Analysis Spreadsheet does not allow the analyst to modify the hours of operation in each mode. To keep the spreadsheet manageable in the near-term, it was assumed that most MEL improvements would involve reductions to the power levels in each mode, not a change to the length of time the MEL spent in each mode. But there are certainly important exceptions, such as control systems that switch electronics into a "hard" off mode instead of

standby mode, or "sleep" features that switch computers from active to low-power mode. The spreadsheet may also be used for existing homes where the actual operating hours for a given MEL may be quite different from the typical values. For these situations, the analyst must calculate "effective" power levels that account for the shift in the number of hours spent in each operating mode. The authors intend to allow operating hours to be changed in the next iteration of the spreadsheet.

Correlation with Floor Area and Number of Bedrooms

The energy used by most MELs tends to be a function of both the size of the house and the number of occupants. For BA analysis, the number of bedrooms is used as a surrogate for number of occupants, which cannot be predicted with much accuracy for a new house. We expect that some MELs are primarily driven by house size, such as vacuum cleaners, smoke detectors, and ground-fault circuit interrupters (GFCIs). Others are driven mainly by the number of occupants, such as microwave ovens, coffee makers, and irons. There are also a few MELs that typically use about the same amount of energy in every home regardless of size and occupancy, such as carbon-monoxide detectors, doorbells, and irrigation timers. These relationships were assumed to take the form shown in Equation 2 and were developed for the Benchmark based on engineering judgment supplemented by RECS data whenever there were explicit drivers of MEL energy documented in the regression results. The resulting relationship between total Benchmark MEL energy, house size, number of bedrooms, and geographic location is described by Equation 3. The characteristics of the house tend to be significant, but not particularly strong, drivers of MEL energy use. This trend is fairly consistent with the results of recent RECS studies (EIA 1999; EIA 2001).

$$E_{MEL} = C_1 + C_2 \times FFA + C_3 \times N_{br} \tag{2}$$

where

E_{MEL} = site electricity for an individual MEL in the Benchmark (kWh/yr)
FFA = finished floor area in the Prototype, including finished basement (ft^2)
N_{br} = number of bedrooms in the Prototype
C_1 = constant base load associated with the MEL
C_2 = multiplier for floor area
C_3 = multiplier for number of bedrooms.

$$E_{MEL, total} = (1625 + 0.418 \times FFA + 259 \times N_{br}) \times F_S \tag{3}$$

where

$E_{MEL, total}$ = total site electricity for all MELs in the Benchmark (kWh/yr)
F_S = state multiplier from Table 1.

Sensible and Latent Loads

The internal load contributions from MELs are very important from a whole-house perspective because of their influence on space-conditioning energy use. Because these internal heat gains have not been studied extensively, NREL used engineering judgment to estimate the fraction of energy used by each MEL that is converted to either a sensible or latent internal load. A few end-uses are nearly always located outdoors and do not affect the internal loads, such as garage door openers, shop tools, and pool heaters. But most MELs deposit nearly all of their

energy use as a sensible load on the house. Certain MELs can contribute to the latent load as well, including aquaria, cooking devices, gas appliances, and heaters used for interior spas and hot tubs. Internal loads associated with cooking are particularly difficult to quantify because much of the energy deposited in the food is ingested by the occupants and is already accounted for as part of the occupant sensible and latent heat gains (Hendron 2004). Overall, we estimate that 66% of MEL energy is converted to sensible heat gain, and 2% is converted to latent heat gain.

State Multipliers

Multipliers for the four most populous states were estimated based on the final electric end-use regression equations developed for the 2001 RECS (EIA 2001). These multipliers are applied to the total MEL end-use consumption for both the prototype and Benchmark. Approximately 50 variables were found by EIA to be statistically significant for predicting MELs, but only 11 were deemed by the authors as appropriate adjustments to the MEL energy in the Benchmark. These variables represent external factors that are most likely associated with climatic differences, tax and code policies, and other variables that would tend to affect the same occupants in the same house differently in different states. The excluded variables represent either physical attributes of a prototype house that are known (such as year of construction and floor area) or physical or financial attributes of the occupants (such as age of homeowner or household income) that cannot be predicted for an individual house based on statewide averages. The final state multipliers were calculated by substituting national average values for the excluded variables, while using state averages for those variables that remained.   The contributions from each of the remaining 11 variables toward the state-to-state differences in Benchmark MEL energy use are shown in Figure 4.

Figure 4. Contributors to Geographic Variations in Benchmark MELs
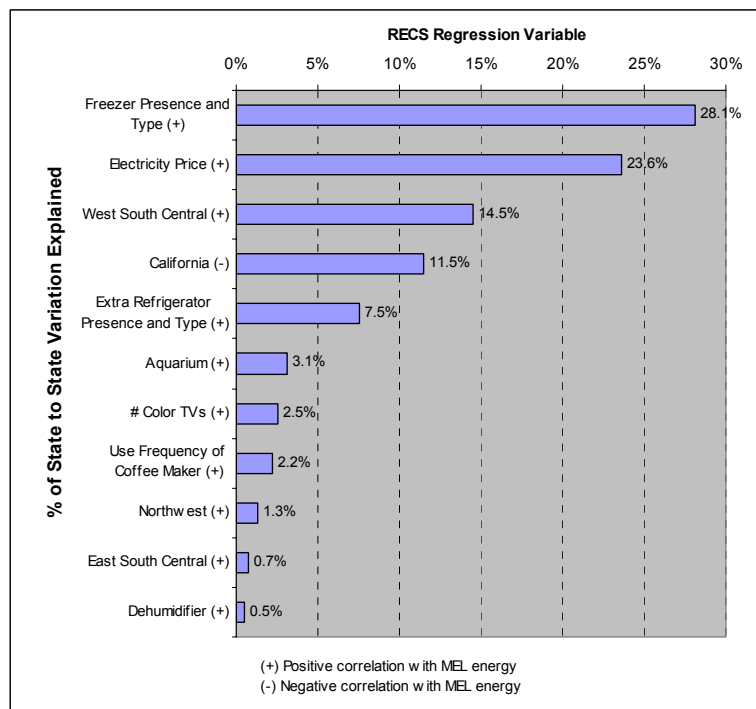
Calculating MEL Savings for a Prototype

When calculating energy savings for a particular package of MELs in a prototype house, the Benchmark must include the same individual MELs that exist in the prototype, with the remainder of the MEL budget lumped into a fixed "Unspecified MEL" category based on national average units per household for both the prototype and Benchmark. For example, if the prototype has four ceiling fans and a home-security system, the Benchmark would have the same number, not 1.4 ceiling fans and 19% of a home-security system. This approach ensures that energy savings is based on the efficiency of MELs, not their presence or absence in a particular house. The MEL Analysis Spreadsheet developed by the authors automates this process.

Conclusions and Next Steps

This paper summarized the development of a consistent methodology for calculating the energy savings associated with efficiency improvements in the Miscellaneous Electric Loads end-use category for residential buildings. The most relevant existing studies by other research organizations were used to the greatest extent possible to ensure accuracy and completeness. Details of the methodology are more thoroughly documented in an analysis spreadsheet posted on the BA website (www.eere.energy.gov/buildings/building_america/pa_resources.html). Although this analysis approach was developed with the needs of BA in mind, it may serve as a useful technique for other energy efficiency programs that target MELs in residential buildings.

The accuracy and realism of the MEL methodology described in this paper may be significantly enhanced by NREL in future years. Research activities will be dictated by BA program requirements and may include the following:

- Treat hours of operation as a variable in the MEL Analysis Spreadsheet
- Fully define the remaining large end-uses in the Benchmark that are currently in the "Fixed MELs" category, such as pool heaters and pumps, hot tubs, well pumps, and gas fireplaces
- Separate dehumidification from the MEL category and treat it as part of space conditioning, if needed to maintain comfortable indoor humidity levels
- Identify the detailed energy drivers for MELs, such as TV screen size, computer monitor type (LCD vs. CRT), and freezer capacity
- Eliminate the state multipliers and develop a more sophisticated approach to the treatment of geographic location and climate
- Quantify the seasonal variation of operating hours for certain MELs, such as ceiling fans, coffee makers, and electric blankets
- Develop hourly profiles for individual MELs.

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