U.S. Residential Miscellaneous Electric Loads Electricity Consumption

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ABSTRACT

Miscellaneous electric loads (MELs) comprise a wide range of devices, ranging from consumer electronics and portable lighting to electric kitchen equipment and ceiling fans. Studies in the late 1990s found that MELs accounted for a significant and growing portion of U.S. residential electricity consumption. Furthermore, more recent studies indicate that MELs could account for more than half of home *total energy* consumption in highly efficient homes. Due to the rapid evolution of the installed base, power draw by mode, and usage of many MELs, most notably consumer electronics, the U.S. Department of Energy commissioned a study to evaluate the per household and national (U.S.) electricity consumption of residential MELs. Using a bottom-up methodology, we developed estimates for the penetration, saturation, average power draw by usage mode, and average annual usage by mode of 21 key and 9 secondary MELs, as well as preliminary evaluations for more that 50 "other" MELs. The more than 5 billion MEL devices consumed about 359 TWh per year, or about 27 percent of residential electricity consumption in 2006. Together, MELs consume more electricity than any other residential end use. Televisions and set-top boxes (25%), portable and outdoor lighting (17%), and PCs (12%, including monitors and peripherals) account for more than half of residential MEL energy consumption.

Introduction

We define miscellaneous electric loads, hereafter referred to as MELs, as electricity-consuming loads that – with the notable exception of outdoor and portable indoor lighting – do not fall under conventional end uses, such as lighting, HVAC, water heating, and refrigeration. Key types of MELs include consumer electronics, outdoor and portable indoor light fixtures, and the myriad of other devices plugged into mains power around the home. Together, MELs appear to account for an increasingly large portion of residential electricity consumption. One study of a wide range of MELs estimated that they accounted for about 25 percent of residential electricity consumption in 1995 (Sanchez et al. 1998). Recently, the U.S. Department of Energy's Energy Information Administration (DOE/EIA) estimated that "other" electricity consumption, combined with televisions and office equipment, represented about 29 percent of U.S. residential annual electricity consumption (AEC) in 2006 and will grow to approximately 36 percent by 2020. This reflects a projected 31 percent increase in per household MELs electricity consumption in the context of a 8 percent growth in floor space per household. In contrast, over this period EIA projects a 4 percent decreases in per household *non*-MEL electricity consumption (EIA 2006).

Several trends appear responsible for the recent and projected increase in residential MEL electricity consumption, many related to the dramatic increases in connectivity and the performance and concurrent decreases in the cost of consumer electronics over this period. First, the installed base of residential MELs has increased significantly, most notably that of consumer electronics, which account for a majority of residential MEL annual electricity consumption

(AEC). For example, the total installed base of TVs, set-top boxes, audio equipment, video equipment, and cellular phones approximately doubled from 1995 to 2006 (TIAX 2007a). Second, the number of distinct MELs has grown, often driven by the increased use and penetration of information and communication technologies (ICT). Third, the average on-mode power draw of some more energy-intensive MELs, such as televisions and desktop PCs, has also increased. Finally, it appears that the *usage* of some more energy-intensive MELs has increased, i.e., again TVs and PCs (and monitors; TIAX 2006, TIAX 2007a).

In addition to its general interest in the level of MEL AEC, the Building Technology Program at DOE (DOE/BT) has a particularly interest in the per-household electricity consumption (HEC) of MELs. Specifically, DOE/BT has a goal of enabling the construction of cost-effective net zero-energy homes (ZEH) by the year 2020. To meet the ZEH objective, building researchers expect that architects will use highly efficient envelope and fenestration technologies to greatly reduce space heating and cooling loads, deploy high-efficiency building equipment to serve the reduced building loads, and use (at presently, more costly) solar energy[1] to power the efficient equipment (see, for example, Anderson et al. 2004).

Simulations of highly efficient home designs indicate that MELs may pose a major barrier to achieving the cost-effective ZEH goal. As the other building loads shrink, MELs represent an increasingly large portion of overall energy use and make it challenging to achieve large (e.g., 50 percent or more) reductions in home *energy* consumption. To site an actual example, one study estimated that MELs account for about 14 percent of energy consumed in a typical new home in the Denver area. Consequently, a new low-energy home in Loveland, Colorado that achieved a 54% reduction in total energy consumption had to reduce non-MEL energy consumption by 65%; MELs accounted for 32 percent of the high-efficiency home's energy consumption (Hendron and Eastment 2006).

Although several studies have analyzed one or more individual MELs (e.g., ADL 1998, Amann 2004, Calwell and Horowitz 2001, Ostendorp et al. 2005, Rosen and Meier 1999a, Rosen and Meier 1999b, Rosen et al. 2001, Sanchez et al. 1998; Hendron and Eastment [2006] summarizes findings from several of these – and other – studies), many of these are dated due to the rapid turnover and evolution of many MELs and reliance on highly uncertain estimates for usage by mode. This study leverages newer studies and information to develop an up-to-date characterization of residential MELs.

To support its strategic planning efforts, DOE/BT contracted TIAX to characterize residential MELs, i.e., to analyze their unit, household, and annual electricity consumption in 2006. This paper summarizes the methodology, results, findings, and recommendations of this study; the full report provides further details, including additional information not presented here about energy-saving opportunities and evaluations for key and secondary MELs (TIAX 2007b).

National Electricity Consumption Calculations

MELs Selected for Further Analysis

A wide range of residential miscellaneous electric loads (MELs) exist, e.g., our preliminary screening identified well in excess of 100 different loads, as have earlier studies (e.g., Sanchez et al. 1998, ADL 1998, Nordman and McMahon 2004, Hendron and Eastment

[1] Typically, photovoltaic panels to meet electric loads and, potentially, solar thermal collectors to meet some portion of space and/or water heating loads.

2006). Due to the scope limitations, however, we could only model the energy consumption of a limited subset of devices. Based on discussions with DOE/BT, we identified and used the following criteria to select MELs for further evaluation:

1. Select loads with the greatest per-household energy consumption
2. Select loads with high penetrations, i.e., greater than half of all households
3. Select devices that the occupants choose and that are not installed by the builder – these cannot be controlled directly by construction specifications
4. In general, do not consider devices that fall under EPAct/EPCA
5. In general, do not consider devices that are part of an existing major end use

We also carried out less refined analyses for two types of loads, *Secondary, Uncommon* loads with high unit electricity consumption (UEC) values but low installed base and *Secondary, Common* devices with moderate UEC values that, in most cases, appear to have a relatively small energy savings potential.

Table 1 lists the thirty MELs selected for evaluation.

Table 1. MELs Selected for Evaluation

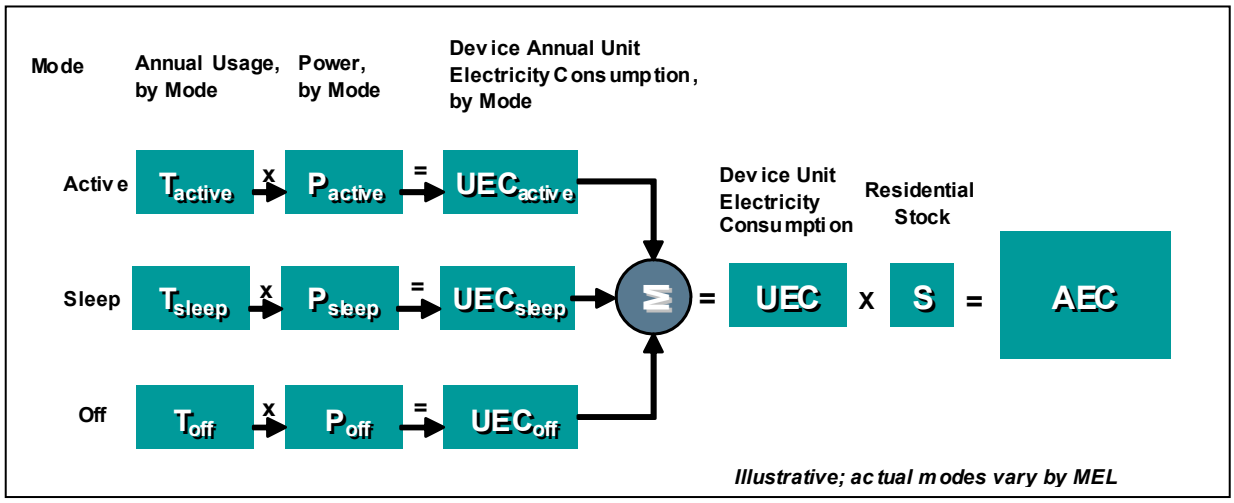
Key (21)	Secondary, Common (5)	Secondary, Uncommon (4)
Ceiling Fan	Hair Dryer	Aquarium
Coffee Machine	Iron	Pool Pump
Compact Audio System	Toaster	Portable Electric Spa
Component Stereo	Toaster Oven	Waterbed Heater
DVD Player	Vacuum Cleaner	
Home Theatre in a Box		
Inkjet Printers + MFDs		
Lighting, Outdoor		
Lighting, Portable		
Microwave Oven		
Modem, Broadband		
Monitors		
PC, Desktop		
PC, Notebook		
Rechargeable Electronics		
Security System, home		
Set-top Box, Cable		
Set-top Box, Satellite		
Television, Analog		
Television, Digital		
VCR (stand-alone)		

Source: TIAX (2007b)

Annual Electricity Consumption (AEC) Calculation Methodology

Figure 1 depicts the methodology used to develop the annual electricity consumption (AEC) estimates for the MELs evaluated.

Figure 1. Annual Electricity Consumption Methodology



Source: ADL (2002)

For each MEL, we calculated the average annual unit electricity consumption (UEC, in kWh) of a single device (e.g., a PC monitor) for an entire year. The UEC equals the sum of the products of the approximate number of hours that each device operates in a residential setting in each power mode relevant to that product and the power draw in each mode. The product of the estimated device stock (i.e., installed base) and the device UEC yields the total AEC (in TWh) for that equipment type. ADL (2002) describes the calculation methodology in greater detail. We evaluated the household electricity consumption (HEC; not shown in Figure 1) in two ways. First, we divided the AEC by the total number of U.S. households in 2006 (115 million; EIA 2006) to calculate the average HEC. In addition, we estimated the typical HEC by mulitplying the UEC for each device by the typical number of units in a household, rounded to the nearest integer[2].

Residential Installed Base

The residential building equipment stock equals the total number of devices in residential buildings, in this case in 2006. The estimates in Table 2 primarily came from published estimates, such as industry market reports and the EIA Residential Energy Consumption Survey (RECS). To clarify, saturation equals the total number of devices divided by the total number of households, while penetration equals the number of households with *at least one* unit divided by the total number of households. TIAX (2007b) provides MEL-specific details about the installed base estimates.

[2] For example, the typical household has two televisions (not 2.4 televisions) and one toaster (not 0.9 toasters). In several instances, we also present average HEC, which equals total MEL AEC divided by the number of households (115 million in 2006; EIA 2006).

Table 2. Installed Base of Residential Key and Secondary MELs in 2006

Type	Miscellaneous Electric Load	Installed Base [millions]	Saturation [devices / HH]	Penetration [% of HH with 1+ devices]
Key	Ceiling Fan	212	1.8	66%
	Coffee Machine	70	0.6	61%
	Compact Audio	76	0.7	46%
	Component Stereo	50	0.4	40%
	DVD Player	120	1.0	74%
	HTIB	25	0.22	17%
	Inkjet + MFDs	101	0.9	68%
	Lighting, Outdoor	258	2.2	75%
	Lighting, Portable	592	5	~100%
	Microwave Oven	110	0.96	96%
	Modem, Broadband	46	0.40	40%
	Monitors	90	0.8	64%
	PC, Desktop	90	0.8	64%
	PC, Notebook	39	0.34	25%
	Rechargeable Electronics	590	5	~100%
	Security System	27	0.23	24%
	STB, Cable	77	0.7	45%
	STB, Satellite	70	0.6	25%
	TV, Analog	237	2.1	89%
	TV, Digital	38	0.33	24%
	VCR (stand-alone)	105	0.9	79%
	Total	**3,000**	**26**	**N/A**
Secondary	Hair Dryer	99	0.9	86%
	Iron	106	0.9	92%
	Toaster	104	0.9	90%
	Toaster Oven	64	0.6	56%
	Vacuum	113	1.0	98%
	Total	**490**	**4**	**N/A**
Uncommon	Aquarium	14.7	0.13	13%
	Pool Pump	7	0.06	6%
	Spa Heater and Pump	3.5	0.03	3%
	Waterbed Heater	4.3	0.03	3.4%
	Total	**30**	**0.3**	**N/A**

Source: TIAX (2007b)

Overall, residential stock estimates appear to have the smallest uncertainty of all three components of device AEC calculations.

Annual Usage by Mode

Annual usage by mode represents the number of hours per year that each device operates in a given mode, averaged over the entire installed base of devices. Most MELs analyzed in our study have at least two distinct operational modes, i.e., on and off, while many have more. Historically, developing accurate estimates for MEL usage has been very challenging due to the expense of collecting data for a statistically significant and representative sample of U.S. households. Furthermore, several MELs, such as consumer electronics (CE), evolve rapidly, in which case their usage profiles may change appreciably over a period of a few years.

In general, relatively few statistically significant and nationally representative *measurements* of residential MEL usage patterns exist. This study primarily uses usage estimates from prior consumer research studies and, in a limited number of cases, small data sets of in-house monitoring of MEL usage, to assess annual usage by mode. Most notably, for consumer electronics, we have used usage profiles developed from recent phone surveys of 2,000 demographically-representative U.S. households about the usage, quantity, and characteristics of twelve CE products. TIAX (2006) and TIAX (2007a) describe the surveys in more detail. Nonetheless, we expect that device usage patterns typically have the greatest uncertainty of any component of the AEC calculations for most MELs. Table 3 presents the annual usage by mode estimates for the MELs selected for evaluation; TIAX (2007b) provides details about the MEL-specific estimates.

Table 3. Average Usage by Mode, Hours per Year

Type	MEL	Active	Idle	Sleep	Off
Key	Ceiling Fan	2,400			6,360
	Coffee Machine	38	229		8,493
	Compact Audio	840	730		7,190
	Component Stereo	1,580	730		6,450
	DVD Player	315	900		7,545
	HTIB	1,580	730		6,450
	Inkjet + MFDs	136	163		8,461
	Lighting, Outdoor	1,020			7,740
	Lighting, Portable	660			8,100
	Microwave Oven	70			8,690
	Modem, Broadband	8,760			
	Monitors	1,861		869	6,029
	PC, Desktop	2,968		333	5,457
	PC, Notebook	2,383		918	5,458
	Rechargeable Electronics	Varies by device, see TIAX (2007b)			
	Security System*		4,990	3,770	
	STB, Cable	2,730			6,030
	STB, Satellite	3,240			5,520
	TV, Analog	1,900			6,860
	TV, Digital	1,900			6,860
	VCR (stand-alone)	156	793		7,811
Secondary	Hair Dryer	44**			
	Iron	39**			
	Toaster	37			
	Toaster Oven	25			
	Vacuum	39**			
Un-common	Aquarium	Varies by component, see TIAX (2007b)			
	Pool Pump	809			7,951
	Spa Heater and Pump	25			8,735
	Waterbed Heater	3,100	5,660		

Source: TIAX (2007b). * Active- and Passive-Standby modes. ** Rest of time unplugged.

Power Draw by Mode

The AEC estimates incorporated power draw data for different MELS for each mode of operation. For each mode, the power draw value represents the best estimate for the average power draw of all of the different devices included in a single MEL. This estimate assumes that annual usage by mode does not vary appreciably with power draw by mode, e.g., that desktop

PCs that draw 120W in active mode do not spend appreciably more hours in active mode per year than desktop PCs that draw 50W in active mode. A recent study investigated this effect for televisions, the device where we expected the most significant deviation from this assumption. On average, larger, more powerful TVs were used more, but energy consumption only increased by 5% when accounting for the power/usage correlation (see TIAX 2007a). We did not, however, analyze this effect for most other MELs due to the dearth of meaningful data, the difficulty and expense of generating this data, and our perception that the magnitude of the error introduced by this simplification is likely on the order of or less than that of the magnitude of other uncertainties in usage patterns.

Table 4 summarizes the power draw by mode values used in the analysis; TIAX (2007b) provides details for each MEL.

Table 4. Average Power Draw by Mode

Type	MEL	Active	Idle	Sleep	Off
Key	Ceiling Fan	35			0
	Coffee Machine	1,100	70		0.4
	Compact Audio	23	16		7
	Component Stereo	45	43		3
	DVD Player	14	10.7		2.9
	HTIB	38	34		0.6
	Inkjet + MFDs	10.5	4.7		2.8
	Lighting, Outdoor	107			0.25
	Lighting, Portable	82			0
	Microwave Oven	1,500			3
	Modem, Broadband	6			
	Monitors	42		1	1
	PC, Desktop	25		2	2
	PC, Notebook	75		4	2
	Rechargeable Electronics	Varies by device, see TIAX (2007b)			
	Security System*		7	7	
	STB, Cable	16			15
	STB, Satellite	15			14
	TV, Analog	See TIAX (2007b)**			4
	TV, Digital	192			4
	VCR (stand-alone)	16	12		4.5
Secondary	Hair Dryer	938			
	Iron	1,350			
	Toaster	1,050			
	Toaster Oven	1,300			
	Vacuum	1,080			
Un-common	Aquarium	Varies by component, see TIAX (2007b)			
	Pool Pump	1,360			0
	Spa Heater and Pump	3,039			225
	Waterbed Heater	350	2		

TIAX (2007b). * Active- and Passive-Standby modes. ** Power draw broken down by TV priority in TIAX (2007b).

For all MELs evaluated, the power draw values for all modes reflect power draw measurements of devices instead of rated power draw values. Rated power draws represent the maximum power that the device's power supply can handle and often exceed typical active power draw values by at least a factor of three (e.g., ADL 2002). Ideally, the power draw values

would come from measurements of a statistically representative sample of products that reflect the installed base of equipment for the entire U.S., i.e., accounting for make, model, and vintage[3]. When this information was available, we employed this strategy, but this level of accuracy was not achieved for most MELs. The sources of power draw data for this study vary by product type, but in general, come from a wide range of measurements reported in prior analyses and limited, targeted measurements by TIAX.

We concluded that the uncertainty in the average power draw by mode values is probably smaller than uncertainties in annual usage for many MELs.

Results

Overall, the key and secondary MELs evaluated consumed about 297TWh of electricity and 3.2 quads of primary energy[4] in 2006. Placed in context, this represents about 22 percent and 15 percent of residential electricity and primary energy consumption[5], respectively[6]. In addition, our preliminary assessment of other MELs found that they consumed approximately 62 TWh of additional electricity consumption, equal to about 5 percent of total residential electricity consumption. Placed in a national context, all of the residential MELs evaluated account for about 10 percent of U.S. electricity consumption and 4 percent of U.S. primary energy consumption in 2006 (TIAX 2007b, EIA 2006).

Even after completing this detailed assessment of MELs, "other"[7] still appears to account for about 7 to 8 percent of residential electricity consumption. Discussions with DOE/EIA indicated that they derived total electricity (and energy) consumption values for the "other" category by comparing total residential sector electricity (or primary energy consumption) consumption estimates to the sum of bottom-up estimates for the different end uses. All of these estimates have some error and uncertainty associated with them, and DOE/EIA confirmed that statistical error probably accounts for most of the apparent "other" energy consumption that remains (Cymbalsky 2007), i.e., most "other" energy consumption is probably *not* real.

It is important to note that the total annual energy consumption (AEC) figures reported in our study overlap with some traditional end uses. For example, our analysis included outdoor and task lighting, even though these are considered part of the lighting end use. Consequently, any use of this study's findings needs to keep in mind these potential overlaps with other studies to avoid double-counting of energy consumption.

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[3] For example, the Australia Greenhouse Office has carried out invasive surveys of more than 100 Australian homes where they measured the power draw by mode of all plug loads in the homes (see Energy Efficient Strategies 2006). Assuming that the homes sampled were truly a representative sample of Australian homes, that sample could approach statistical significance.

[4] Primary energy, as opposed to site energy, takes into account the energy consumed at electric power plants to generate electricity. In 2006, every kWh of site electricity requires the consumption of an average of 10,831 Btus to generate, transmit, and distribute (EIA 2006). The total shown also includes site fuel energy consumption, most notably natural gas, heating fuel, and propane used for space heating and water heating.

[5] As portable and outdoor lighting electricity and energy consumption values are considered MELs for the purposes of this study, we subtracted those values from the EIA (2006) estimates for lighting energy consumption.

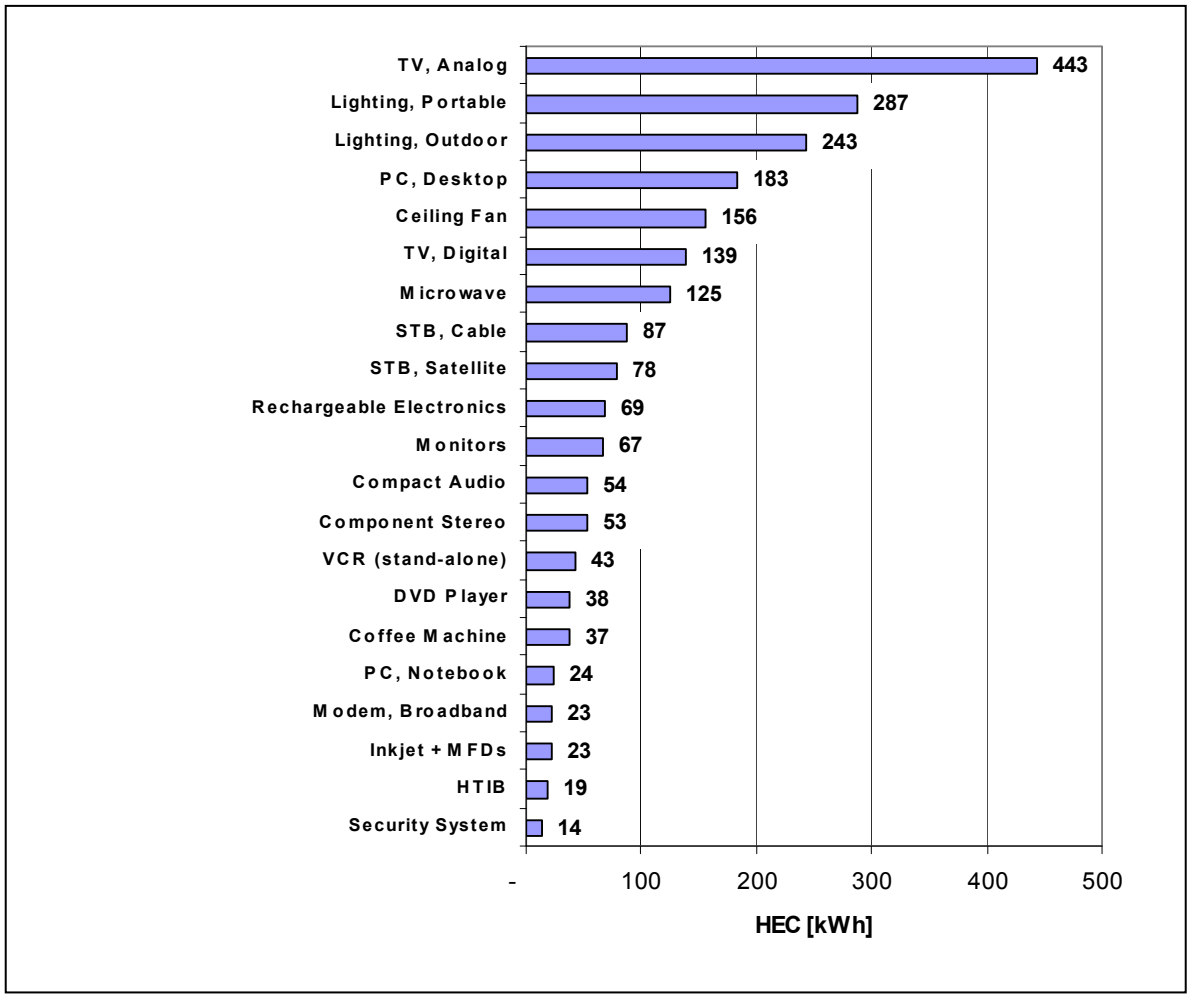
[6] If portable and outdoor lighting are not counted as MELs, these percentages decrease to 17 and 12 percent, respectively.

[7] EIA (2006) states that other includes small electric devices, heating elements, and motors not included in other end uses. In addition, Cymbalsky (2007) indicates that "other" includes Christmas lights and wine coolers and under-bar refrigerators.

We evaluated MEL household electricity consumption (HEC) in two ways. First, we calculated the *average* HEC, which equals the total electricity consumption of key and secondary MELs divided by the 115 million U.S. households in 2006. Second, we calculated the *typical* HEC, based on the number of each MEL analyzed in a typical household based on penetration and installed base data. For example, the average value will reflect the energy consumed by 2.4 televisions and 0.03 water beds, while the typical household value will reflect two televisions and zero water beds. The calculated average and typical HEC values for the MELs analyzed (key and secondary, excluding other) are within four percent of each other, i.e. 2,580 and 2,490 kWh/year, respectively.

Televisions (23%), portable and outdoor lighting (21%), and PCs (12%, including monitors and peripherals) are the largest contributors to average HEC (see Figure 2) and, together, represent more than half of average MEL HEC.

Figure 2. Average Household Electricity Consumption for the Key MELs



Source: TIAX (2007b)

The unit electricity consumption (UEC) of the key MELs vary by more than an order of magnitude (see Table 5). Digital televisions have the highest value, followed by desktop PCs and analog TVs. Relative to most key MELs, the secondary, uncommon loads have higher UECs while the secondary, common loads have more moderate UECs.

Table 5. Residential Installed Base

Type	MEL	UEC [kWh]
Key	Ceiling Fan	84
	Coffee Machine	61
	Compact Audio	81
	Component Stereo	122
	DVD Player	37
	HTIB	89
	Inkjet + MFDs	26
	Lighting, Outdoor	110
	Lighting, Portable	54
	Microwave Oven	131
	Modem, Broadband	53
	Monitors	85
	PC, Desktop	235
	PC, Notebook	72
	Rechargeable Electronics	13
	Security System	61
	STB, Cable	133
	STB, Satellite	129
	TV, Analog	216
	TV, Digital	392
	VCR (stand-alone)	47
	Total	**N/A**
Secondary	Hair Dryer	42
	Iron	53
	Toaster	39
	Toaster Oven	33
	Vacuum	42
	Total	**N/A**
Un-common	Aquarium	210
	Pool Pump	1,100
	Spa Heater and Pump	2,040
	Waterbed Heater	1,100
	Total	**N/A**

Source: TIAX (2007b)

Breaking down HEC by mode for the key and secondary MELs, active mode accounted for about 80 percent of average HEC, with idle, sleep, and off accounting for about 7 percent, 0.1 percent, and 13 percent of HEC, respectively. Different modes account, however, for varying portions of the overall UEC for different MELs. In general, active mode accounts for the largest portion of the MELs with the highest UEC, such as televisions, desktop PCs, while low-power modes account for a significant portion of the UEC of many audio and video products. The active mode accounts for almost all of the UEC of the secondary loads, both common and uncommon loads.

Conclusions

We carried out a comprehensive characterization of residential MEL electricity consumption in 2006 using a bottom-up approach. Overall, we estimate that MELs consumed 359 TWh of electricity, equal to 3.9 quad of primary energy. As such, MELs account for the

largest portion of residential electricity consumption of any end use, about 27 percent, and the second largest portion of residential primary energy consumption, about 19% (spaces heating is about 30%; EIA 2006). Televisions (23%), portable and outdoor lighting (21%), and PCs (12%, including monitors and peripherals) are the largest contributors to average HEC and, together, represent just over half of average MEL HEC.

Will MELs continue to grow and account for an even greater portion of residential electricity consumption as the EIA projects (EIA 2006)? To help answer that question, we recently completed an updated version of TIAX (2007b) that developed scenario-based projections of future MELs electricity consumption circa 2020. For each scenario, we developed projections for both the installed base and UEC (using a bottom-up methodology) for the key MELs. In sum, we found that the average HEC of the key MELs ranged from 1,960 to 2,810 kWh (as compared to 2,580kWh in 2006). Thus, although MELs will continue to consume a significant quantity of electricity and pose challenges to attaining zero-energy homes, their electricity consumption will likely not grow dramatically beyond current levels.

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