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Miscellaneous Electric Loads: Characterization and Energy Savings Potential

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Abstract

Over time, miscellaneous electric loads (MELs) are expected to increase both in magnitude and share of residential and commercial building energy consumption. This trend is most apparent in North America, but it is also occurring in Japan and Europe. However, the contribution of MELs to building energy use is not currently well understood, both because the products in this category are transforming rapidly and the definition and classification of MELs is ambiguous. This study estimated the national energy consumption of 36 MELs using best-available data and found them to comprise 12% of delivered electricity to the U.S. residential and commercial building sectors. If 26 of these MELs were replaced with the most energy-efficient product models available on the market, their energy consumption could be halved to 6% of delivered electricity. National energy models will better account for building energy consumption by incorporating the MELs data collected and analyzed for this study, leading to improved policy decisions.

Keywords: miscellaneous electric loads; U.S. national energy consumption; energy savings potential; buildings; end uses; forecast

1. Introduction

Substantial energy efficiency improvements have been made in the equipment associated with the major electricity end uses, such as refrigerators, heating and cooling systems, and lighting. The result has been a leveling, and sometimes even a decline, in building energy use in many developed countries (EIA, 2019a; IEA, 2018). Further reductions are envisioned (as shown by different scenarios in Figure 1). However, reductions in total building energy consumption are limited (if not altogether eliminated) by a growth in energy consumption from often-uncategorized equipment that is not considered a major end use. This collection of uncategorized equipment, which is often labelled “miscellaneous electric loads (MELs)” among other names (“Other” in Figure 1), is therefore of rising importance in energy policy. What activities and devices comprise it? Is it growing or shrinking? What technologies can be applied to reduce the energy consumption of the devices inside this collection? Curiously, little research has been directed to this collection of uncategorized devices over the past decade, even though it can now represent the largest collective end use in some buildings. This paper estimates the energy use and energy savings potential of common MELs in residences and commercial buildings. Even though this analysis pertains to the United States (U.S.), the findings can assist energy forecasters and policymakers in many other countries.

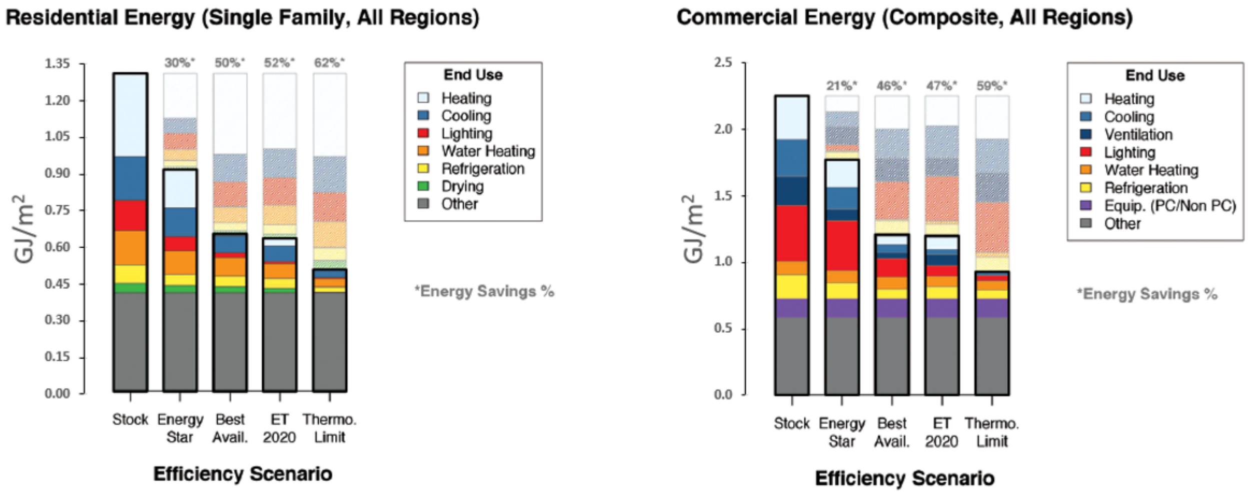

Figure 1: Forecasted Energy Consumption (gigajoules per square meter, GJ/m^2) by End Use Category and Efficiency Scenario in Residential and Commercial Buildings for 2014. Note that while energy savings are forecast for the major end use categories, no energy savings are forecast for the "Other" category. Adapted from DOE, 2019a.

This article begins by considering the variety of existing definitions and taxonomies for MELs. Then, early field measurements of MELs are discussed and a characterization of MELs' energy consumption in the U.S. is provided. Data sources and test data for MELs are also described before the study's results and conclusions are presented.

2. Definitions and Taxonomies of Miscellaneous Electric Loads

Miscellaneous electric loads are typically defined through exclusion from other loads, and their definition can change by organization or study, based on the nature of inquiry. A MEL can be broadly defined as any electric load that does not fulfill a primary building service of HVAC, lighting, or water heating, which in the U.S. is the definition used by the ANSI/ASHRAE/IES 90.1 standard for buildings (Dirks and Rauch, 2012). Another common definition for MELs refers to them as any electric load outside of a building's core functions of HVAC, lighting, water heating, and refrigeration (Roth et al., 2008). In this case, refrigeration is considered a core building function and therefore not categorized as a MEL. While task lights are typically categorized as lighting, they can also be categorized as MELs in certain instances, which can pose challenges when comparing lighting energy use between studies (Hafer, 2015). Plug-in electric vehicles present a similar issue because they are categorized as transportation in certain instances and MELs in other cases (Huckett et al., 2017). The types of end uses classified as MELs can also vary across building types. Collectively, this results in ambiguity as to which end uses are MELs and which are not, and in which circumstances. This can pose a challenge for ensuring consistent energy accounting and avoiding double-counting and other issues in energy demand forecasts.

The inconsistency and confusion over defining MELs has hindered the establishment of a common MELs taxonomy.[1] A taxonomy for MELs is important because, unlike most other end use categories, the MELs category contains a vast array of products, delivering an equally large number of services. Several taxonomies have been developed for MELs, but none have been well accepted and widely adopted across research organizations and governing bodies. In a literature review, Nordman and Sanchez (2006) identified 28 different proposed (or implied) taxonomies for MELs, most of which were categorized by the primary function or service of the end use. In particular, the U.S. Energy Information Administration (EIA) adopted an ad hoc strategy for its MELs taxonomy in the Residential Energy Consumption Survey (RECS) (EIA, 2017). Since nearly half of residential electricity consumption was attributed to the "other uses" category, and a significant fraction was simply unclassified, EIA added 20 new product characterizations to the 2015 RECS and reduced the unclassified consumption to approximately 13% of the total (EIA, 2019b). EIA's taxonomy therefore simply considered a residential product a MEL if it were (1) not in an existing core end-use category, and (2) forecasted to account for a significant amount of national residential energy consumption.

Major ambiguities go unaddressed when classifying MELs through exclusion. First, MELs represent an extraordinarily diverse collection of physical products and services with new ones continuously introduced into the market. Second, many MELs supplement a core end use, such as microwaves supplementing stoves and ovens. Third, some MELs definitions refer to physical attributes (e.g., plug loads) while others refer to services (e.g., network equipment) or location (e.g., small kitchen appliances). The lack of a consistent definition and common taxonomy for MELs should not hinder the development of policies to address their energy use. For that reason, the authors have focused on characterizing the energy use of MELs.

3. Early Field Measurements of MELs

There are significant technical challenges to measuring MELs (Kamilaris et al., 2014). As a result, relatively few studies have been undertaken. One of the earliest known explorations of the energy consumption of MELs was documented by Meier over three decades ago (Meier, 1987). It was a compilation of available field measurements. Since then, various studies have attempted to characterize MELs more comprehensively or in a specific sector. For example, Black et al. (2012) and Christiansen et al. (2015) characterized MELs use in hospitals; Roth et al. (2014) and Urban et al. (2017) studied a variety of consumer electronics; Goetzler et al. (2013) studied electric motors; and Bush et al. (2009) and ENERGY STAR (2011) characterized coffeemakers. Additionally, substantial reductions in the energy consumption of many MELs through applications of new technologies have been identified, including set-top boxes (Lee and Yun,

[1] A *taxonomy* is an agreed-upon structure for naming and categorizing products within an end-use category. A taxonomy of MELs would facilitate communication and understanding by providing a consistent framework with clear boundaries, distinguishing MELs from one another and core end uses.

2011), office equipment (Choi et al., 2015), wireless access infrastructure (Gomez et al., 2013), and elevators (Lin and Lian, 2017).

Despite the recognition of MELs' growing share of building electricity consumption and identified savings potential in individual products, there have been few comprehensive attempts to estimate potential savings from more energy efficient MELs. The National Renewable Energy Laboratory devised a methodology to estimate energy savings from improved MELs, developed a research plan for reducing MELs energy consumption in zero-energy homes, and studied how to reduce plug and process loads for office buildings, respectively (Barley et al., 2008; Hendron and Eastment, 2006; Lobato et al., 2011). In 2010, McKenney et al. published a paper suggesting that 35% energy savings could be obtained by replacing the 2008 commercial installed base (i.e., number of units of a product that are in use) of MELs with best-in-class devices (McKenney et al., 2010); however, this study is more than a decade old at this point. More recently, Kwong et al. (2018) studied MELs energy savings opportunities relative to the existing regulatory landscape for Malaysian residential and commercial buildings. One could also make preliminary estimates of energy savings for certain MELs based on studies that provide energy use estimates for baseline and efficient models (for example, Urban et al., 2017). However, for many MELs, baseline energy consumption is poorly defined, and product features vary widely.

4. Selection of MELs for Further Investigation

The MELs analyzed in this study were derived from EIA forecasts released in the 2019 Annual Energy Outlook (AEO), which reports modeled projections of U.S. energy markets through 2050 (EIA, 2019c). AEO forecasts are generated using the National Energy Modeling System (NEMS), which is an integrated assessment model that relies on robust economic and energy market data to generate projections, including estimates for end-use energy consumption by sector and category (EIA, 2019c).

For the residential and commercial building sectors, the 2019 AEO forecasts electricity consumption for 16 major end-use categories (EIA, 2019c): space heating,[2] space cooling, ventilation, water heating, lighting, refrigeration, freezers, cooking, clothes washers,[3] clothes dryers, dishwashers, televisions and related equipment,[4] computers and related equipment,[5] office equipment, furnace fans and boiler circulation pumps, and other uses.[6] While EIA does not specifically define MELs in the 2019 AEO, the NEMS methodology for projecting end-use

[2] Includes fuel consumption for district services.

[3] Does not include water heating portion of the load.

[4] Includes televisions, set-top boxes, home theater systems, DVD players, and video game consoles.

[5] Includes desktop and laptop computers, monitors, and networking equipment.

[6] Includes (but is not limited to) small electric devices, heating elements, transformers, elevators, escalators, off-road electric vehicles, laboratory fume hoods, commercial laundry equipment, coffee brewers, water service equipment, medical imaging and other medical equipment, and motors not accounted for in the major end-use categories. It specifically excludes electric vehicles, which were assigned to the transportation sector.

electricity consumption offers differentiation for separating end uses typically regarded as MELs from those typically regarded as core end uses.

For building end uses prioritized in NEMS,[7] EIA estimates the installed cost, energy efficiency, and lifetime of individual end uses, and then uses these data to estimate turnover of the installed base (i.e., when all existing units in use are replaced by new units) to project national end-use electricity consumption (EIA, 2019d, e). For the remaining end uses,[8] which are considered MELs for the purpose of this study, EIA estimates only the saturation rate (i.e., units per household) and unit energy consumption (UEC)[9] of the given end use (EIA, 2017). Since lifetime, cost, and baseline energy efficiency are not proposed for these MELs, NEMS does not estimate the rate at which the installed base of individual MELs turns over nor the corresponding energy and cost impacts of introducing energy efficiency measures in the baseline case.[10] These data limitations offer an opportunity to improve the ability of NEMS to forecast the electricity consumption of MELs in future AEOs.

The 2019 AEO forecasts MELs to increase both in share and magnitude of total building electricity consumption through 2050. Figure 2 depicts EIA's 2019 forecast of delivered electricity between core loads and MELs in residential and commercial buildings. Together, MELs account for nearly 46% of forecasted delivered electricity consumption in residential and commercial buildings. Among the individual end-use categories, the "other uses" category dominates, accounting for 34% of all residential and commercial electricity purchased in 2019 (EIA, 2019c). Furthermore, MELs are forecasted to increase to nearly 54% of all residential and commercial electricity purchased in 2050, with the "other uses" category alone accounting for nearly 40%.

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[7] Space heating, space cooling, water heating, ventilation, refrigeration, cooking, residential clothes dryers, freezers, lighting, residential clothes washers, and dishwashers.

[8] Televisions and related equipment, computers and related equipment, office equipment, furnace fans and boiler circulation pumps, and other uses.

[9] Average annual energy consumption per end use unit.

[10] *Baseline case* refers to EIA's forecast assuming future trends follow those of the past under normal economic conditions.

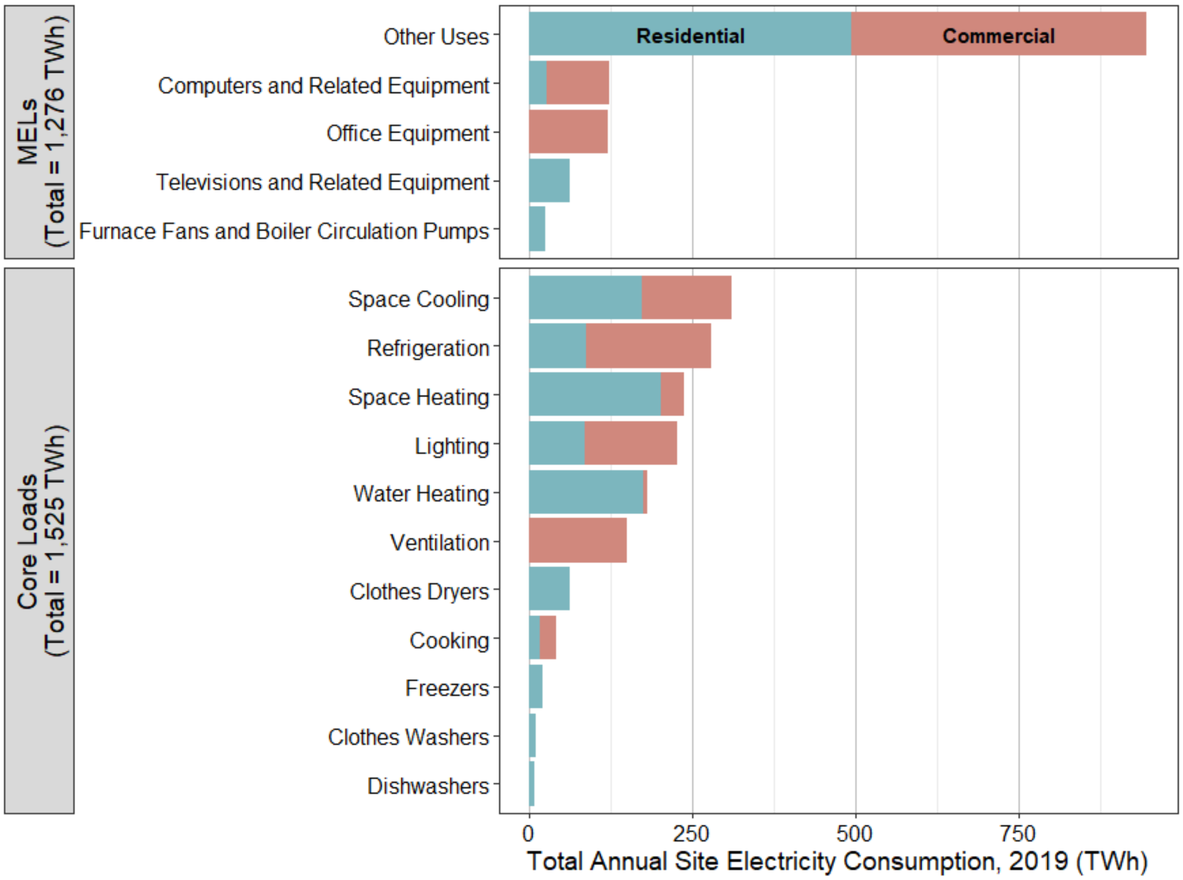

Figure 2: Forecasted Delivered Electricity Consumption (terawatt-hours, TWh) in Residential and Commercial Buildings by End-Use Category for 2019 (based on EIA, 2019c)

The substantial and growing share of MELs electricity consumption in buildings conveys the importance of characterizing their individual electricity usage, as well as understanding and identifying effective energy efficiency measures to limit their footprint. This is a challenge because MELs are so diverse. For example, some MELs are present at very high saturations and have low per-unit electricity consumption (e.g., battery chargers), whereas other MELs are present at low saturations but have high per-unit electricity consumption (e.g., commercial kitchen ventilation systems). In addition, the electricity consumption of certain MELs strongly depends on usage patterns (e.g., microwaves), while other MELs have consumption that is fairly constant (e.g., residential network equipment). To complicate matters, the composition of MELs is continuously changing as new products (e.g., voice assistants) are introduced and old products (e.g., water beds) fade from the market over time.

The prioritization and selection of MELs for this study was based on three considerations: (1) end uses for which NEMS lacks baseline technology cost, energy performance, and lifetime data, (2) availability of viable data, and (3) each end use's percentage of residential and commercial sector electricity consumption for the year 2019 according to AEO 2019, as shown in Table 1 (Fares et al., 2018). The shares of electricity consumption for residential MELs listed in Table 1 sum to equal the total 2019 electricity consumption estimates of the "other uses," "televisions and related equipment," "computers and related equipment," and "furnace fans and boiler circulation pumps" categories combined (refer to Figure 2), representing 42% of all residential electricity consumption. The shares of electricity consumption for the commercial MELs in Table 1 sum to equal the total 2019 electricity consumption estimates of the "other uses," "office equipment," and "computers and related equipment" categories combined (refer to Figure 2), representing 49% of all commercial electricity consumption. Using the underlying NEMS data (and end-use names) provided in Table 1, a set of MELs (names italicized in Table 1) was selected for this study as a starting point to collect comprehensive data for EIA to potentially integrate into NEMS. Unfortunately, NEMS combined several categories (such as pool pumps and heaters), which creates inconsistencies in nomenclature. Moreover, certain end uses are explicitly analyzed in one building sector, but not the other. Collectively, these ambiguities illustrate the difficulties in establishing a consistent naming scheme for MELs.

Table 1: Share of Total Sector Site Electricity Consumption in 2019 for Major Residential and Commercial MELs

Residential MELs		**Commercial MELs**	
End Use	**Fraction of 2019 Site Electricity Consumption (%)**	**End Use**	**Fraction of 2019 Site Electricity Consumption (%)**
Other Electric	27.4	Other Electric	18.1
Televisions	1.9	*Office Equipment - Non-PCs*	8.8
Set-Top Boxes	1.8	*Desktop PCs*	7.1
Furnace Fans/Boiler Pumps	1.7	Water Services	4.9
Pool Heater/Pumps	1.5	*Dry Transformers*	3.1
Ceiling Fans	1.4	*Kitchen Ventilation*	2.8
Microwaves	1.0	IT Equipment	1.1
Dehumidifiers	0.9	Security Systems	0.8
Aboveground Spas	0.7	*Fume Hoods*	0.6
Desktop PCs	0.6	Telecommunication	0.5
Wine Coolers	0.5	Non-Road Electric Vehicles	0.3

Monitors	0.5	*Lab Refrigerators and Freezers*	0.3
Laptops	0.4	*Elevators*	0.2
Coffeemakers	0.3	*Coffee Brewers*	0.2
Network Equipment	0.3	*Medical Imaging*	0.2
Rechargeable Batteries	0.3	*Laundry*	0.1
Home Theater	0.2	Office UPS	0.1
DVD Players	0.2	UPS Data Center	0.1
Video Game Consoles	0.2	*Escalators*[a]	0.0
Security Systems	0.1	*Large Video Boards*[a]	0.0
Total	**42**	*VOIP Phones*[a]	0.0
		Video Displays[a]	0.0
		Total	**49**

[a] Escalators, large video boards, video displays, and VOIP phones comprised less than 0.1% of commercial sector electricity consumption.

Note: UPS = uninterruptible power supply, VOIP = Voice Over Internet Protocol

5. Methodology to Estimate National Energy Consumption

A bottom-up approach was used to characterize the annual national energy consumption (NEC) of each MEL in this study based on the typical unit in the installed base. This called for determining the average power draw (in watts, W) and usage (hours/year) by operating mode for each MEL. Then, using the percentage of time spent in active and standby/off modes over the course of a year, a weighted-average power draw for active and standby/off modes was developed from the available data. Active mode power was a weighted average of on, idle, navigation, and sleep mode power, weighted by the average hours per year in each mode, as applicable (Urban et al., 2017). Similarly, the standby/off mode was a weighted average of networked standby, standby, and off modes using the average hours per year in each of those modes, as applicable. The result was an annual unit energy consumption (UEC), calculated as follows:

$$UEC = \frac{(P_{active} \times HOU_{active}) + (P_{standby} \times HOU_{standby})}{1{,}000} \qquad (1)$$

where UEC is the annual unit energy consumption in kilowatt-hours (kWh); P_{active} and $P_{standby}$ are the weighted-average power consumption for active and standby/off modes, respectively, in watts; and HOU_{active} and $HOU_{standby}$ are the number of annual operating hours in active and standby/off modes, respectively.

For three MELs—low-voltage distribution transformers (LVDTs), commercial clothes washers, and wine coolers—modal power and usage data were either inapplicable to operation or unavailable. For instance, LVDTs incur losses dependent upon their load profiles. The results of DOE rulemaking analyses were relied upon in this study for the characterization of these three MELs.

To determine the annual national energy consumption (NEC) of each MEL in the study, the following equation was used:

$$NEC = \frac{UEC \times Installed\ Base}{10^9} \tag{2}$$

where *NEC* is annual national energy consumption in terawatt-hours. Estimates of the installed base were obtained from diverse sources because there is no single source for this information.

To estimate potential national energy savings from the introduction or increased market penetration of energy efficient product designs/technologies, data were collected for the most efficient product models sold in the market for 26 MELs in this study for which data were available. Energy savings were calculated for a technical potential scenario. This means an underlying assumption was made that the estimated energy savings would be based on instantaneously replacing the installed base for a particular MEL with the most efficient product for that MEL (i.e., natural turnover rates were not considered). The resulting national energy savings projections can be sensitive to relatively small changes in the input values for determining UEC and NEC values. Fares et al. (2018) demonstrated the sensitivity of projected national energy savings to changes in the underlying input data. The next section describes the sources of input data that were used in this study.

6. Data Sources

Locating reliable data to characterize MELs is notoriously difficult. Researchers and organizations traditionally responsible for measurement and data collection have largely neglected MELs because they either consume too little energy on a per-unit basis, or do not have a large enough installed base to make an appreciable impact on overall energy consumption (Fares et al., 2018). Therefore, data from a wide variety of sources, including non-traditional sources, were employed to understand the scale and impact of the MELs considered in this study.

6.1 Minimum Energy Efficiency Performance Standards

Several nations have established minimum energy efficiency performance standards (MEPS) as a means of reducing the energy consumption of major end uses. The standards levels are typically established through an analysis of the cost effectiveness for achieving the lower energy use as well as aggregate national impact. In the U.S., EU, and Japan, the most comprehensive characterizations of MELs are the rulemaking analyses conducted in support of federal and state MEPS.[11] The development of mandatory MEPS calls for analytical, data-based determinations. Federal MEPS rulemakings conducted by the DOE characterize a product's

[11] In the U.S., MEPS are more generally called *energy conservation standards* (ECS).

lifetime, as well as national shipments for a range of efficiency levels, as part of the Life-Cycle Cost (LCC) analysis and National Impact Analysis (NIA) (LBNL, 2019). DOE conducts rulemaking analyses primarily for end uses identified in a series of legislation by Congress, such as those listed in 42 U.S. Code § 6292. As a result, while DOE has conducted analyses and set MEPS for more than 60 end uses (i.e., covered products), only a subset of MELs are included among them (DOE, 2017). Beyond those end uses specified in congressional legislation, the U.S. Secretary of Energy can establish MEPS for any end use that exceeds 100 kWh annually per household and that is deemed appropriate by the Secretary (42 U.S. Code § 6292(b)). Portable air conditioners are an example of an end use that the Secretary of Energy has pursued for MEPS using this special classification (DOE 2016). For this study, data from DOE rulemakings were used for nine MELs.[12]

U.S. State-level MEPS rulemakings provide similar cost, energy efficiency, and lifetime information for MELs; but, again, for only a subset of MELs. The California Energy Commission (CEC) has conducted a recent MEPS rulemaking for computers, computer monitors, and signage displays (California Energy Commission, 2017). Energy use data from CEC rulemakings were relied upon broadly for four MELs in this study.[13] A common data limitation for state-level MEPS rulemakings is that these rulemakings often provide shipment or installed base data specifically for the state of interest, which is generally inadequate for determining national-level shipments and installed units.

In addition to mandatory Federal and State-level MEPS, there are voluntary specifications and programs that may rely on cost, lifetime, and shipment data to determine the appropriate energy efficiency levels for participation. ENERGY STAR® is a voluntary labeling program run by the U.S. Environmental Protection Agency intended to identify and promote the most energy-efficient product models sold in the market. When setting voluntary specifications, ENERGY STAR may collect and analyze cost, energy efficiency, lifetime, and shipment data to determine specifications for participation, as outlined in its guiding principles (ENERGY STAR, 2012). While ENERGY STAR data sets may be incomplete in some cases, they can still provide insight into an aspect of energy efficiency. For instance, ENERGY STAR collected product model data for its determination of specifications for Voice-over-Internet Protocol (VoIP) phones. ENERGY STAR specification development data were useful for characterizing VoIP phones, televisions, and printers/multifunction devices.

6.2 Product Test Data

Databases of product test results may contain performance and efficiency data for certain MELs. Examples include DOE's Compliance Certification Management System (CCMS) Database (DOE, 2019b), ENERGY STAR Certified Products lists (ENERGY STAR, 2019)

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[12] Specifically, commercial ceiling fans, commercial clothes washers, coolers and cooler-refrigeration combination products, dehumidifiers, low-voltage dry distribution transformers, microwaves, pool pumps, residential ceiling fans, and residential pool heaters.

[13] Specifically, commercial video displays, computer monitors, portable electric spas, and televisions.

(which capture only the most efficient models sold on the market), and the CEC Appliance Database (California Energy Commission, 2019). The data provided in such databases can be useful for developing a national-average efficiency distribution for a given MELs product or identifying the most efficient product models sold in the market. However, relying on data from multiple databases requires that the test data are directly comparable (i.e., the data come from the same test procedures, or equivalent measurements).

6.3 Field Studies

Governments, utilities, regional energy offices, and other entities have completed numerous large-scale field studies that provide insight into the performance, modal hours of operation, and service lifetime of MELs. The Northwest Energy Efficiency Alliance's (NEEA) Residential Building Stock Assessment (NEEA, 2016a), Commercial Building Stock Assessment (NEEA, 2016b), and Industrial Facilities Site Assessments (NEEA, 2016c) are informative field studies for understanding the breadth of energy use in homes, buildings, and facilities, respectively. Several international studies of standby power consumption—an important component of many MELs—have been undertaken and illustrated differences in products and countries (de Almeida et al., 2011; Meier et al., 2004; Patrão et al., 2017). Field study data can be scaled to represent national energy implications, or compared with data from other sources to develop national-level projections prior to incorporation into national energy models.

6.4 Reports

Journal articles and reports have covered a variety of topics related to the prevalence and energy use of MELs. These reports are typically published by government agencies (EIA, 2017), utilities (Kisch et al., 2014), consultants (Roth et al., 2008), trade associations (Urban et al., 2017), universities (Hafer, 2015), and other non-profit organizations (Kwatra et al., 2013). While many MEL-specific reports cover one or more key modeling inputs for a variety of MELs, it is uncommon for a single article or report to provide all the national-level inputs required for modeling MELs in national energy demand models. The diversity of inputs creates the possibility for inconsistent definitions, costs, installed base estimates, performance, and other assumptions.

6.5 Data Aggregators

Data aggregators extract specific types of data from the web or a select group of websites. Data aggregators are an emerging resource for understanding the prevalence and energy performance of certain end uses. One is an online data aggregator, Enervee, that provides energy performance and retail price data for certain MELs such as TVs, computer monitors, game consoles, sound bars, tablets, dehumidifiers, air purifiers, and pool pumps (Enervee, 2019). However, since Enervee uses a proprietary energy rating to characterize a product's energy consumption instead of providing energy consumption in kilowatt-hours or natural gas therms, its usefulness to researchers is limited primarily to the collection of retail price data. In addition, data sourced from Enervee calls for manual data entry or extraction, since downloading data is not a feature that Enervee provides.

7. Results

This study characterized the prevalence and energy consumption of 36 MELs in the residential and commercial sectors. Cumulatively, these 36 MELs represent 2.3 billion units in the U.S. installed base, consuming approximately 350 TWh of annual national electricity.[14] This corresponds to 12% of all delivered electricity in the residential and commercial sectors combined (EIA, 2019f) and more than 240 million metric tons of carbon dioxide emitted (EPA, 2019). To put this in perspective, emissions from these 36 MELs are equivalent to the emissions produced from 52 million cars (EPA, 2019).

The characterization of MELs was organized based on the completeness and confidence of the collected data. MELs were separated into three groups: partially-understood, mostly-understood, and well-understood. Of the 36 MELs studied, 10 were considered "partially-understood," since energy consumption and installed base data were available for only the average or typical product in the installed base. Data on the most efficient product models sold in the market were either unavailable or sparse. These 10 MELs represent approximately 270 million products in the installed base, consuming approximately 50 TWh annually (using equations 1 and 2).

The "mostly-understood" category is composed of 17 MELs. For this category, data were collected and analyzed for both the typical product in the installed base and most efficient product model sold in the market. However, since DOE has not established MEPS for these MELs, none of the data were sourced from DOE rulemaking analyses and were thus considered less robust. The 17 MELs in this category represent 1.8 billion units in the installed base, consuming approximately 190 TWh annually.

Nine MELs were considered "well-understood," since the characterization of both the typical product in the installed base and most efficient product model sold in the market were based upon data collected and analyzed for DOE to justify and establish MEPS. These nine MELs represent more than 200 million products in the installed base, consuming about 100 TWh annually.

Figure 3 provides estimated electricity consumption and potential electricity savings (TWh) of each MEL by group. The total length of the bars indicates the 2019 delivered electricity for each MEL. The portion of the bars shaded red indicates the potential savings available for that MEL if the installed base were converted to the most efficient product representing that MEL. Based on the available data, savings estimates are only provided for MELs in the mostly-understood and well-understood categories.

[14] In-text estimates were rounded to two significant digits.

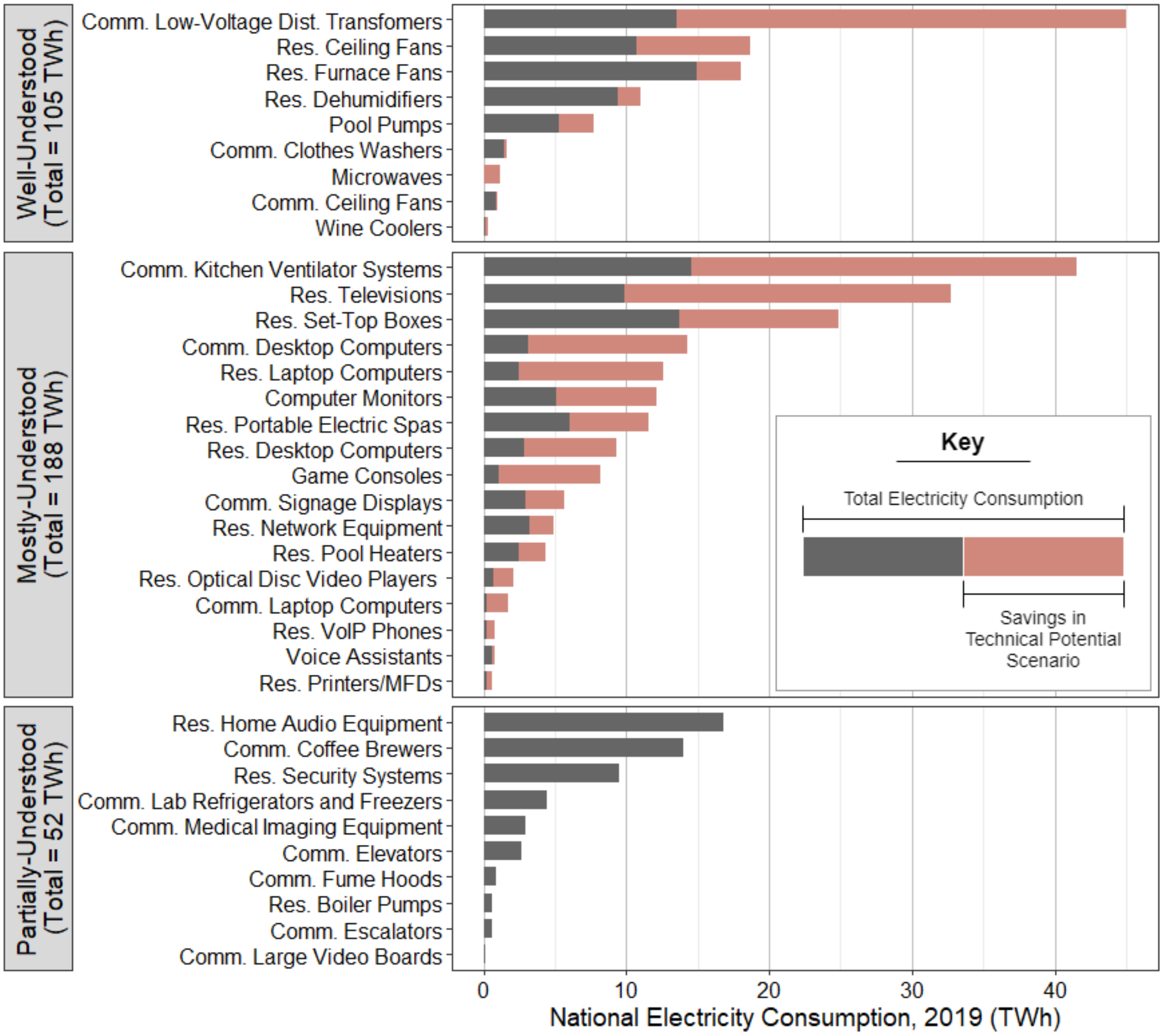

Figure 3: Delivered Electricity Consumption and Potential Electricity Savings of Each MEL by Group in 2019

Together, the 26 MELs in the "well-understood" and "mostly-understood" groups consume approximately 290 TWh nationally per year, corresponding to 11% of residential and commercial building electricity use. Since data were collected for the most efficient product models sold in the market for MELs in these groups, technical potential electricity savings estimates were determined assuming the current U.S. installed base were replaced (i.e., turned over) with only the most efficient product models sold in the market. Realistically, replacing the installed base takes years to achieve as products run out their useful lives. However, collectively, these savings amount to approximately 170 TWh annually, representing a 57% reduction in electricity consumption for these 26 MELs, and a 6% overall decrease of delivered electricity to the residential and commercial sectors. If these theoretical savings were fulfilled, carbon emissions would decrease by 120 million metric tons per year, which is equivalent to the emissions from 26 million cars driven each year (EPA, 2019). Among these 26 MELs, two offer a significant energy savings opportunity: low-voltage dry distribution transformers (LVDTs) and commercial kitchen ventilation systems.

LVDTs have the highest energy use among the MELs studied, with a national electricity consumption of 45 TWh per year. The typical LVDT[15] in the installed base operates with an annual energy consumption of approximately 7,600 kWh (in the form of conversion losses), whereas the most efficient LVDT design[16] operates with an energy consumption of 2,300 kWh annually. If the LVDT installed base were "turned over" to the most efficient design, it would amount to energy savings of more than 30 TWh of per year.

Commercial kitchen ventilation systems are the second most energy-consuming MEL in the study, with a national energy consumption of nearly 42 TWh per year. The typical commercial kitchen ventilator consumes 49,000 kWh per year, while the most efficient product model consumes 17,000 kWh annually.[17] If the commercial kitchen ventilator installed base were replaced to the most efficient product model, energy savings would amount to nearly 30 TWh annually.

8. Conclusions and Policy Implications

MELs consume a significant amount of electricity in the residential and commercial building sectors, but their individual energy use and savings potential have been overlooked or are insufficiently characterized. The lack of a widely adopted definition and taxonomy for MELs complicates the aggregation and analysis of previous research since it is unclear which end uses constitute a MEL. The establishment of a MELs definition and taxonomy would resolve ambiguities and double-counting, but researchers should not perceive the lack of a single definition as a barrier for investigating energy efficiency and load shifting opportunities for this important end-use category.

We characterized 36 MELs comprising 12% of residential and commercial electricity consumption in the U.S. and found that the energy consumption of these MELs could be halved by instantaneously replacing the current installed base with the most energy efficient product models sold in the market (i.e., in a technical potential scenario). The miscellaneous and uncategorized loads are often dismissed as unimportant from both energy consumption and savings perspectives. This investigation demonstrates that the miscellaneous loads are large and ripe targets for energy-saving strategies. These data still need to be incorporated into energy demand models to improve forecasts of national energy consumption. Policymakers rely upon

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[15] The Typical LVDT had a weighted average size of 102 kilovolt-ampere (kVA) and efficiency of 98.1%.

[16] For this study, the most efficient LVDT design consists of a stack amorphous ribbon metal core capable of 99.4% efficiency.

[17] The most efficient commercial kitchen ventilation system is equipped with a demand control ventilation (DCV) energy management system, which optimizes energy efficiency by reducing the exhaust and make-up air fan speed through leveraging temperature and optic sensors

these models to determine how to manage energy generation, distribution, and demand across utility service territories, states, and the nation.

MELs are a large, diverse, and dynamic end use category that must be included in any successful electricity and climate strategy. Further research on partially-understood MELs is still needed to better identify the extent to which energy efficiency differentiation exists in the marketplace. In addition, strengthening the underlying data for MELs in the mostly-understood category and gaining a better understanding of the diffusion rates of energy efficient technologies will improve the accuracy of national modeling forecasts. This could be accomplished through more extensive surveys and closer tracking of product shipments, combined with field monitoring.

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Data Availability

The data collected and analyzed for this study have been published online at the following location: https://doi.org/10.5281/zenodo.4012692 (Hosbach et al., 2020).

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