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Authors
Fares, Robert
Sofos, Marina
Langevin, Jared
et al.

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9 authors, including:

Marina Sofos
U.S. Department of Energy

Jared Langevin
Lawrence Berkeley National Laboratory

Improving Characterization of Miscellaneous Energy Loads in Energy Demand Models

Robert L. Fares, Marina Sofos, Building Technologies Office, U.S. Department of Energy
Jared Langevin, Robert Hosbach, Alan Meier, Lawrence Berkeley National Laboratory
Joshua Butzbaugh, Paul Ehrlich, Pacific Northwest National Laboratory

ABSTRACT

Miscellaneous energy loads (MELs) comprise a significant and growing portion of total building energy consumption. However relatively little is known about the products that make up MELs end uses, and MELs are modeled with less granularity than major end uses in energy demand models such as the U.S. Department of Energy's Scout energy efficiency impact analysis tool or the U.S. Energy Information Administration's National Energy Modeling System (NEMS). This paper identifies differences in the way MELs versus major building end uses are modeled, and then reviews potential sources of MELs baseline technology data that could be used to improve their characterization in energy demand models. Case studies of dry distribution transformers, hot water circulation pumps, and Japanese-style automatic bidets are presented to compare and contrast the level of baseline data available for different end uses. We show that there is potential to use data from energy conservation standards and other sources to significantly improve representation of some MELs in energy demand models, while other emerging MELs require further data collection before they can be modeled precisely.

Introduction and Motivation

In recent years, there has been growing interest amongst the building energy efficiency community in reducing energy consumption from miscellaneous energy loads (MELs), or loads outside a building's core functions of heating, cooling, ventilation, lighting, and domestic hot water heating. Interest in reducing MELs consumption is driven by the fact that both their share of total building consumption and the magnitude of their energy use are expected to increase over time. Figure 1 below illustrates projected source energy consumption from MELs and core building end uses between now and 2045 based on the U.S. Energy Information Administration (EIA) Annual Energy Outlook 2017 (U.S. Energy Information Administration 2017a). Source energy consumption is calculated from the EIA site consumption data using ENERGY STAR site-to-source ratios (ENERGY STAR 2018b).

Often, there are inconsistencies in how exactly MELs end uses are defined and distinguished from major building end uses. Here we specifically define MELs as all building end uses without baseline technology cost, energy performance, and product lifetime characterized by the U.S. EIA and integrated into the National Energy Modeling System (NEMS). Table 1 below identifies each of the MELs end uses in the residential and commercial sectors, and their share of total sector source energy consumption in year 2017 calculated using EIA Annual Energy Outlook 2017 data (U.S. Energy Information Administration 2017a). In both the residential and commercial sectors, MELs comprise approximately 30% of total sector energy consumption, and approximately half of MELs consumption is from undefined end uses — consumption EIA does not assign to particular building end uses.

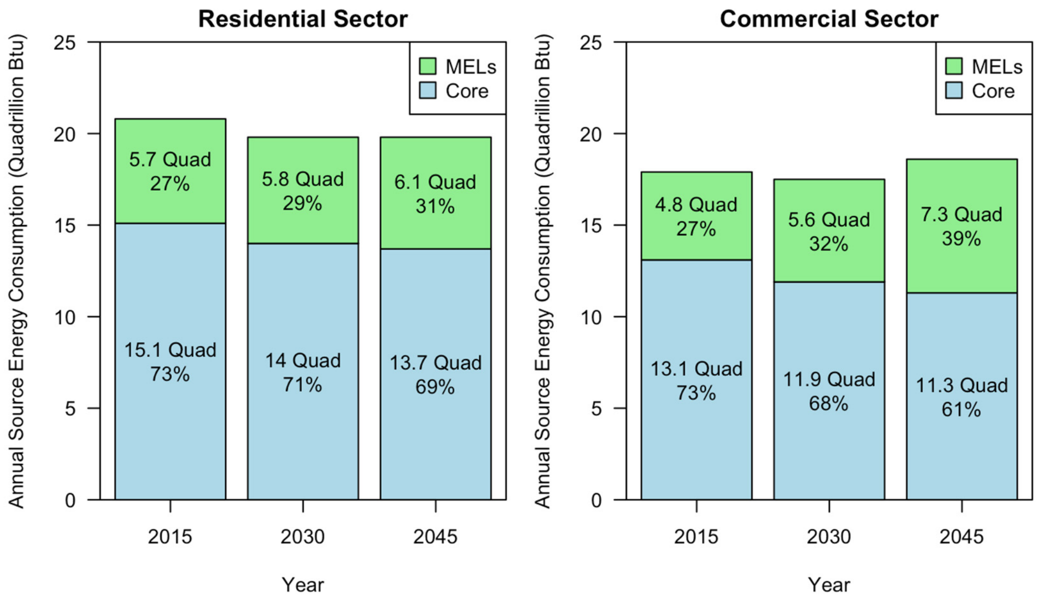

Figure 1. Both total consumption and the share of building consumption from miscellaneous energy loads (MELs) is expected to increase between now and 2045 according to the 2017 U.S. Energy Information Administration Annual Energy Outlook (U.S. Energy Information Administration 2017a). Source energy calculated using ENERGY STAR site-to-source ratios (ENERGY STAR 2018b).

Table 1. Residential and commercial MELs and their portion of total sector source energy consumption in year 2017 (U.S. Energy Information Administration 2017a).

Residential MELs		Commercial MELs	
End Use	**% of 2017 Residential Source Energy Consumption**	**End Use**	**% of 2017 Commercial Source Energy Consumption**
Other/Undefined	16%	Other/Undefined	11%
Set Top Boxes	1.9%	Office Equipment - PCs	5.7%
Furnace Fans/Boiler Pumps	1.7%	Office Equipment - Non-PCs	3.9%
TV	1.7%	Dry Transformers	2.2%
Ceiling Fan	1.4%	Kitchen Ventilation	2.0%
Pool Heater/Pumps	1.1%	Non-Road Electric Vehicles	0.72%
Microwaves	0.77%	Security Systems	0.54%
Desktop PC	0.55%	Lab Fridges and Freezers	0.22%
Spas	0.53%	Coffee Brewers	0.15%
Laptops	0.47%	Elevators	0.15%
Wine Coolers	0.36%	Video Displays	0.15%
Dehumidifiers	0.35%	Laundry	0.07%
Network Equipment	0.25%	Fume Hoods	0.05%

Coffee Makers	0.25%	Escalators	0.03%
Monitors	0.24%	Large Video Boards	0.01%
Rechargeable Batteries	0.22%	Medical Imaging	No Data
DVD Players	0.17%	**Total**	**27%**
Home Theater	0.16%		
Video Game Consoles	0.11%		
Security Systems	0.10%		
Total	**28%**		

Despite the fact that MELs represent a significant and growing portion of total building energy consumption, relatively little is known about the products that comprise MELs end uses.

For all core building end uses, EIA estimates the installed cost, energy efficiency, and lifetime of individual products and equipment, and then estimates stock turnover to estimate overall building energy consumption (U.S. Energy Information Administration 2017c, 2017b). The most recent equipment costs and efficiency report is available from EIA (Navigant Consulting Inc. and SAIC 2016), and provides detailed data for major (i.e., non-MEL) end uses.

For MELs end uses, EIA only estimates the saturation rate, or the number of devices per household, and the unit energy consumption (UEC), or the average energy consumption per device (Navigant Consulting Inc., SAIC, and Leidos 2017). Without information about the lifetime, cost, and efficiency of a baseline MELs product, it is impossible to explicitly estimate the rate at which the stock of products will turnover and the corresponding energy and cost impacts of introducing a new product.

To illustrate how gaps in these baseline data can yield substantial uncertainty around the evaluation of prospective MELs technologies, we perform a sensitivity analysis using Scout, a tool developed by the U.S. Department of Energy's Building Technologies Office's (BTO) for estimating the national impact potential of building efficiency technologies (Harris et al. 2016). In Scout, the national energy reduction potential of a prospective energy conservation measure (ECM) m is calculated as follows:

$$\Delta E(y) = E_b(y) f_m(y) f_e(y) + E_b(y) \sum_{k=0}^{y-1} f_m(k) f_e(k) \qquad (1)$$

Where $\Delta E(y)$ is the total primary energy savings for the ECM in simulation year y; $E_b(y)$ is the total baseline energy use segment to which the ECM applies in year y; $f_m(y)$ is the fraction of the total baseline market that the ECM competes for and captures in year y; $f_e(y)$ is the fraction of energy use that the ECM saves at the unit level relative to a comparable baseline technology in year y; and the right hand term represents energy savings from previous years.

In Eq. 1, the captured market fraction $f_m(y)$ varies according to adoption scenario, ranging from a technical potential case where the entire baseline market is competed in each year to a maximum adoption potential case where only the portion of the baseline market that is new or up for retrofit or replacement is competed in each year. In the latter case, the baseline replacement rate is determined by the lifetime of a comparable baseline technology. Additionally, $f_m(y)$ accounts for competition between ECMs with overlapping markets, apportioning market shares based on ECM incremental capital and operating costs over the comparable baseline technology.

Given the integral role that baseline technology cost, efficiency, and lifetime inputs thus play in ECM energy savings calculations, savings results are highly sensitive to the values chosen for these inputs. Indeed, Figure 2 shows that baseline cost, efficiency, and lifetime variability strongly affects the timing and magnitude of maximum adoption potential savings for commercial MELs ECMs, also changing the market-competitiveness of these ECMs.

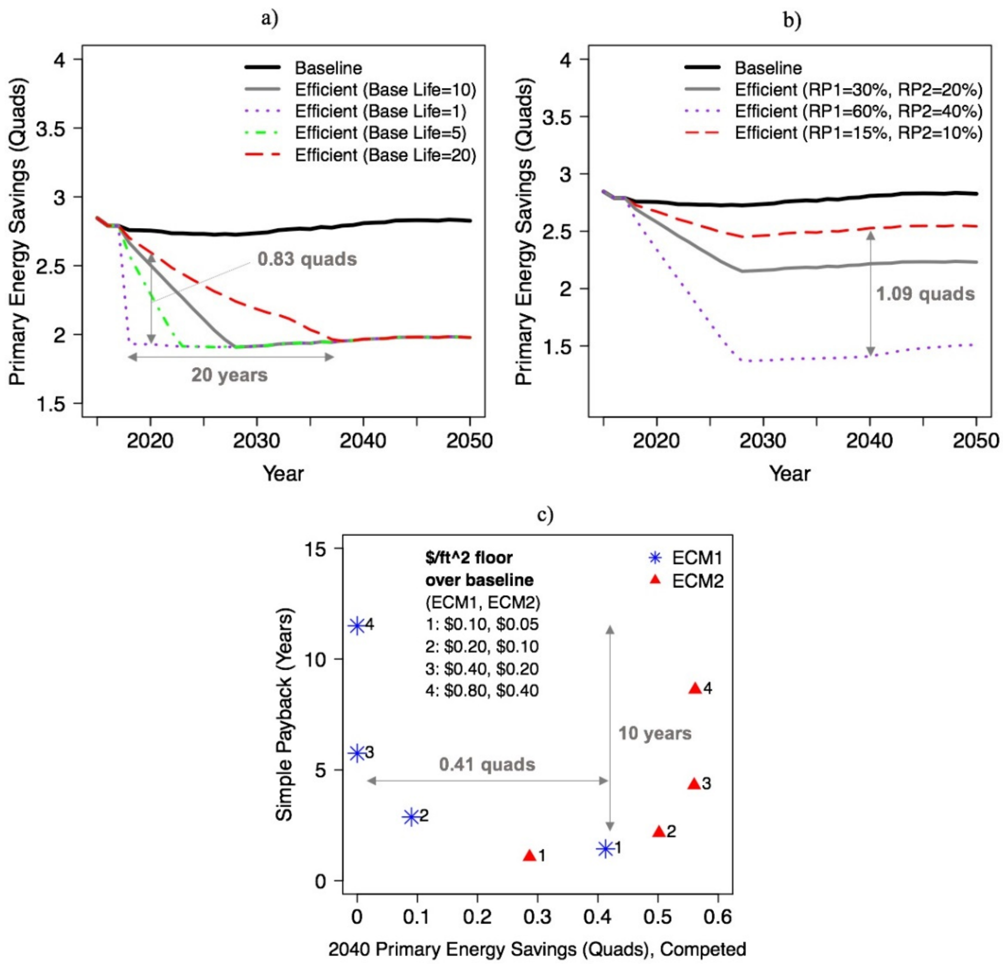

Figure 2. Effects of baseline MELs technology assumptions on the energy savings and cost effectiveness of Scout ECMs/ECM portfolios that apply to all defined commercial MELs from the 2017 Annual Energy Outlook (U.S. Energy Information Administration 2017a). a) Given a MELs ECM introduced in 2018 with a 30% relative energy performance improvement (RP) over a comparable baseline MELs technology, modifying the baseline technology lifetime from the current default of 10 years to a range between 1 and 20 years yields a 20 year spread in the projected point of full ECM market saturation; in 2020, this translates to a spread of 0.83 quads in projected ECM energy savings. b) Given an ECM portfolio with two competing MELs ECMs at 30% and 20% RP, modifying the comparable baseline technology performance such that it ranges from halving the ECM RPs (15%/10%) to doubling them (60%/40%) yields a spread of 1.09 quads in projected portfolio savings in 2040. c) Given an ECM portfolio with two competing MELs ECMs at 30% and 20% RP where the first ECM's incremental cost is double that of the second ECM, modifying the baseline MELs technology cost such that both ECMs' incremental costs are successively doubled yields an ECM payback range of up to 10 years and savings range of up to 0.41 quads.

The results illustrated in Figure 2 show there is a need to improve characterization of MELs end uses in energy demand models to understand where MELs energy conservation efforts should be targeted. The objective of this paper is to review existing sources of MELs baseline technology performance data and demonstrate how available data could be used to improve characterization of MELs end uses in building energy demand models The remainder of this paper is organized as follows: the Literature Review section reviews studies that have characterized MELs consumption and savings potential; the Methodology and Process section review sources of MELs baseline technology data and discusses data preparation needed to integrate this data with energy demand models; the Case Studies section presents examples dry distribution transformers, Japanese-style automatic bidets, and hot water circulation pumps to compare and contract data availability for different MELs; and the Conclusion section summarizes our findings and identifies future work.

Background

The first documented exploration of MELs occurred in 1987 (Meier 1987), with a more detailed examination in 1992. The focus on the residential sector can be attributed in part to the comparatively limited data in the literature for analysis in the commercial sector and a need to measure load profiles of key MELs for different climate zones and building types to better understand and control their energy consumption (Kamilaris 2014). Even in the residential sector, the development of a bottom-up model of energy consumption using historical shipment data and forecasts was based on estimates from disparate sources and was limited by sparse and non-existent data (Sanchez 1998).

Characteristics of MELs along with methods for reducing their consumption have subsequently been examined to the greatest extent possible in applications such as new homes (Brown 2007), hospitals (Black 2014 and Christiansen 2015), consumer electronics (Roth 2014 and Consumer Technology Association 2017), coffee makers (Bush 2009 and Energy Star 2011), and electric motors in both residential and commercial applications (Goetzler 2013). However, these characteristics are largely dependent on the type of end-use load or device. Few studies document both energy consumption and load shapes for the selected loads analyzed (Parker 2003).

Standby modes were introduced in the last two decades as strategies for improving the efficiency of plug load MELs (IEA 2001), however the portion of their energy consumption attributed to “idle” or “sleep” modes is still not fully characterized nor communicated to consumers (Delforge 2015). Further research and field studies are required to characterize, for example, the impacts of “connected standby” mode and the impact of dynamic power draw and device modifications (Consumer Technology Association 2017). An experimental study of a well-instrumented single building suggests that plug loads require monitoring for at least two months, including half of the floor area and 10-20 % of the key device categories, to accurately represent time-resolved energy consumption (Lanzisera 2013).

While numerous studies have documented the energy consumption characteristics of individual MELs end uses and strategies for reducing their consumption, few studies have identified and sought to address a fundamental shortcoming of MELs characterization methods: MELs end uses are generally not characterized and modeled with as much granularity as major end uses. The aim of this paper is to fill this knowledge gap by demonstrating how available MELs end use data could be used to improve MELs characterization in energy demand models.

Methodology and Process

The following subsections provide key sources of input data for various MELs, followed by a description of data preparation for input into Scout, NEMS, or a similar energy demand model. A technology's per-unit installed cost, energy performance, and lifetime are required to properly characterize products and analyze the energy and carbon impacts of energy conservation measures (Harris et al. 2016). Various (and sometimes disparate) data sources typically need to be combined in order to fully and properly characterize a given MEL.

Sources of Input Data

Almost by definition, the data required to accurately characterize MELs are difficult to find. The individual products either consume too little energy to matter or are too few to make an impact. The following sections summarize information available from various data sources.

National and State Appliance Efficiency Standards Rulemakings

One of the best sources of MELs baseline data are the rulemakings for DOE's appliance energy conservation standards (ECS). A national impact analysis is typically completed to ascertain the energy savings and net present value of total purchaser benefits of proposed efficiency standards. Inputs to the national impact analysis include equipment energy efficiency (forecasted over the analysis period), total installed cost, as well as product lifetime and shipments data (i.e., all of the key inputs for Scout or another energy demand model) (Lawrence Berkeley National Laboratory-Energy Analysis and Environmental Impacts Division n.d.).

While these rulemakings are an ideal source of MELs baseline data, DOE ECS rulemakings have been conducted for only a handful of MELs (e.g., ceiling fans and distribution transformers). In some cases, state-level ECS rulemakings can provide similar cost, efficiency, and lifetime information for MELs that have not yet been analyzed through a DOE rulemaking. As an example, the California Energy Commission has conducted a recent ECS rulemaking on computers, computer monitors, and signage displays (California Energy Commission 2017). However, state-level ECS rulemakings would not normally provide national-level shipments data, so this information would need to be collected from other sources.

EIA Sources

The EIA publishes various potential sources of information for MELs, including national energy consumption surveys and reports (U.S. Energy Information Administration n.d., n.d.; Navigant Consulting Inc., SAIC, and Leidos 2017). While each of these sources may provide a subset of key MELs data, outside sources will be required to fill in data gaps. For example, the survey data do not include detailed information on equipment cost and efficiency.

Test Results Databases and Field Data

Numerous databases exist that contain product-specific test results. Some examples include DOE's Compliance Certification Database, ENERGY STAR Certified Products lists (which capture only the most efficient models currently on the market), and the California Energy Commission Appliance Database (U.S. Department of Energy 2018; ENERGY STAR 2018a; California Energy Commission 2018). While these data sources do not provide product cost and shipments data, they do in most cases provide individual product-level efficiency results that can help to inform a national-average efficiency distribution for a given MELs product.

Additionally, some large-scale field studies have been completed that can provide insight into a given MEL's energy use and service lifetime. Good examples are the Residential Building Stock Assessment and Commercial Building Stock Assessment, which are conducted by the Northwest Energy Efficiency Alliance (Northwest Energy Efficiency Alliance 2016a, 2016b, 2016c). For field studies such as these, care must be taken to ensure that the results are scaled to be nationally-representative or that the results are combined with other data sources to ensure valid results at the national level prior to use in Scout or a similar energy demand model.

Literature

Finally, there are various papers and reports that cover different aspects of MELs, as summarized in the Literature Review section of this paper. Many MELs-specific papers are wide-ranging and provide one or more key inputs for a variety of MELs (Urban et al. 2017); however, in most cases no single paper or report will provide all of the key national-level inputs for Scout or a similar energy demand model. This creates opportunities for inconsistencies in definitions, costs, stocks, and other assumptions.

Data Preparation

As mentioned in the Sources of Input Data subsection, it is imperative that care is taken to ensure any available data are reliable and nationally-representative of the MELs product under consideration. It is not uncommon for different sources to provide disparate national stock estimates for the same MELs product, for example. In these cases, the underlying information sources and assumptions used to come to these estimates must be evaluated. In the case of field studies, care must be taken not to assume a regional field study's results are representative on a national level. Furthermore, for regional studies that have scaled their results to be nationally-representative, one should understand the scaling methodology to ensure validity of the final results.

Finally, in nearly every instance, the available data will need to be aggregated to be nationally-representative of a given MELs product. This can be a challenge, as individual products for a given MELs product may have widely disparate costs, efficiencies, stock and shipments, and even service lifetime. National ECS rulemakings typically handle this challenge by analyzing representative units at various efficiency levels for each of a set of determined product classes. As an example, DOE analyzed representative units in five separate product classes of ceiling fans (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy 2017). The national impact analysis is then conducted using these representative units, and a national-average installed cost, unit energy consumption, efficiency, and service lifetime can be obtained for a given year by weighting each representative unit and product class by its installed stock for that year, relative to the installed stock of the other representative units and product classes. For data coming from sources other than ECS rulemakings, this aggregation is not as straightforward and may require other intermediate data combination and aggregation steps. Finally, in some instances the only available data are national-level estimates of the key model inputs for a MEL; assuming those data are reliable, they can be used directly until more detailed data are collected and/or published.

Case Studies

Aggregating and analyzing MELs stock, lifetime, energy use, and cost data can improve modeling and forecasting of U.S. commercial energy consumption across a range of scenarios. However, each product has unique characteristics and modeling challenges. We present below three examples to illustrate some uncertainties in stocks, costs, energy use, and savings that arise.

Low-voltage dry distribution transformers (LVDT) serve industrial and commercial facilities on the customer-side by stepping down three-phase power from utilities to voltage levels (e.g., 208/120 volts) distributed internally to end uses. It falls into the MELs category because it is an end use without baseline technology cost, energy performance, and product lifetime characterized by NEMS. In this case, however, the DOE rulemaking process has assessed the technology and energy-savings potential (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy 2013a). The Final Rule Technical Support Document (TSD), Lifecycle Cost Analysis Spreadsheet, and National Impacts Analysis spreadsheet developed for this rulemaking offer a comprehensive set of LVDT data, including no-load losses, load losses, installed cost, and device lifetime for individual LVDT design lines (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy 2013b). These data can be incorporated into modeling tools, such as Scout, to forecast other scenarios for LVDT energy use and the impact that these scenarios have on national commercial energy consumption (Harris et al. 2016). For example, the max-tech[1] LVDT design would decrease national LVDT energy losses to an estimated 12.6 TWh per year after stock turnover, which is a savings of 18.6 TWh per year beyond the current standard (shown in Figure 3).

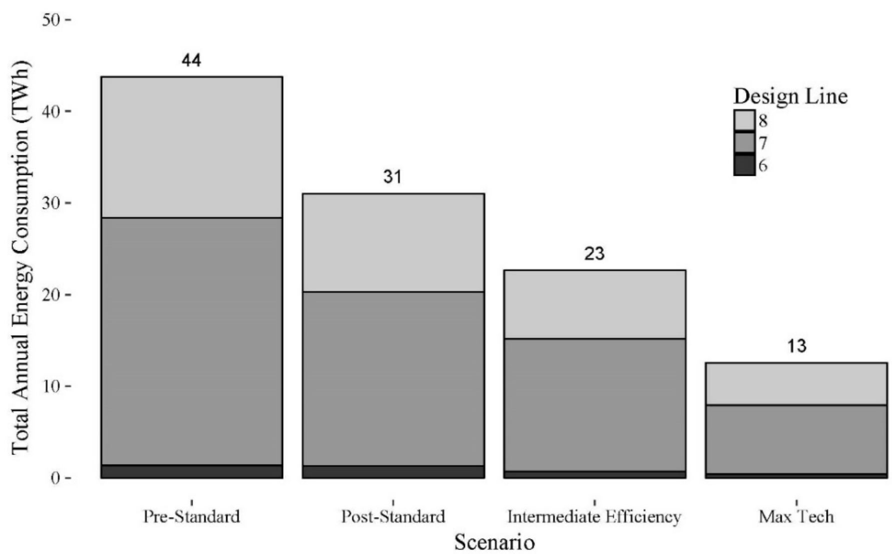

Figure 3. LVDT national annual energy consumption across four scenarios of technological energy efficiency improvements after stock turnover. Annual energy consumption was projected using sourced data for design line energy use, efficiency, and stock. *Sources*: (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy 2013b) and (Navigant Consulting Inc., SAIC, and Leidos 2017).

Transformers represents a kind of best case MEL because the necessary modeling inputs have been carefully studied. In contrast, the Japanese-style automatic bidet (or "washlet") is an

[1] In the context of LVDTs, max tech refers to highest possible efficiency for stepping down power

example of a new MEL that has zero presence today but could be widely adopted in both the commercial and residential markets in the next decade. These fixtures typically have heated seats and a small warm-water spray to operate as a bottom-washer or bidet. Many units have fans to blow warm air and speed drying and newer models have night lights, electrolyzed water generators, and motor-operated seats. The washlets first appeared in Japanese hotels but are now present in almost all Japanese homes and hotels. They are just now appearing in the US market and almost exclusively in the residential market. However, there is good reason to assume that hotels will begin adopting them (like in Japan).

A typical washlet consumes 200 kWh/year (Lopes et al. 2005). If washlets achieve a saturation of 20% in hotel rooms and 30% in homes – less than half that found in Japan today – then their combined energy use will be about 8 TWh/year.

Domestic hot water circulation pumps are another MEL. These pumps circulate domestic hot water to ensure immediate delivery of hot water in both commercial and residential buildings. They are used extensively in large commercial buildings and occasionally in homes and small commercial buildings with long hot water pipe runs. The pump itself — the MEL — uses electricity, but the circulation of hot water increases energy consumption by the water heater (electricity or gas). The pump is treated as a stand-alone MEL instead of a component within water heating because NEMS does not explicitly address it.

Typical residential hot water circulation pumps are rated at 25 W (Schmidt 2011). They can operate continuously, via a programmed schedule, or under the supervision of other controls. One study (Klein 2015) found that, depending on the configuration and control strategy, the pump consumed 4 - 150 kWh/year and caused the electric water heater to use an extra 600 kWh/year.

The national consumption of circulation pumps would be roughly 3 TWh/year if they reach a penetration of 30% in single-family homes and 20% in small commercial buildings. The circulating pumps induce a further 9 TWh/year in the electric water heaters.

These case studies illustrate the diversity in commercial MELs and the characteristics that need to be taken into account. Note that the electricity impacts of all three MELs are roughly comparable; however, the levels of information about them are vastly different.

Conclusion

This paper identified the differences between how MELs end uses and major building end uses are treated in building energy demand models, identified sources of input data that could improve the granularity of MELs modeling, and then presented case studies of three MELs to compare and contrast the level of baseline data available for different end uses. We showed that sufficient data exist to model stock turnover for commercial building distribution transformers, but there is a lack of sufficient data for other emerging MELs.

DOE ECS rulemaking data exist for a number of the MELs end uses identified in Table 1. In the residential sector, these include: ceiling fans, dehumidifiers, furnace fans, microwaves, pool pumps, pool heaters, rechargeable batteries, set top boxes, and wine coolers. In the commercial sector, these include: distribution transformers and clothes washers (U.S. Department of Energy 2018). The shipments, product cost, lifetime, and efficiency data available in these ECS rulemakings could be used to improve the modeling granularity for MELs end uses in Scout, NEMS, and any similar building energy demand model.

Based on these findings, the research community could improve the granularity of MELs end uses in building energy consumption models. We have shown that the requisite data to fully model stock turnover exists for many MELs end uses, and MELs comprise a significant and growing portion of total building energy consumption. Accurately modeling MELs consumption and energy efficiency potential will help to reduce consumption from this growing end use.

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