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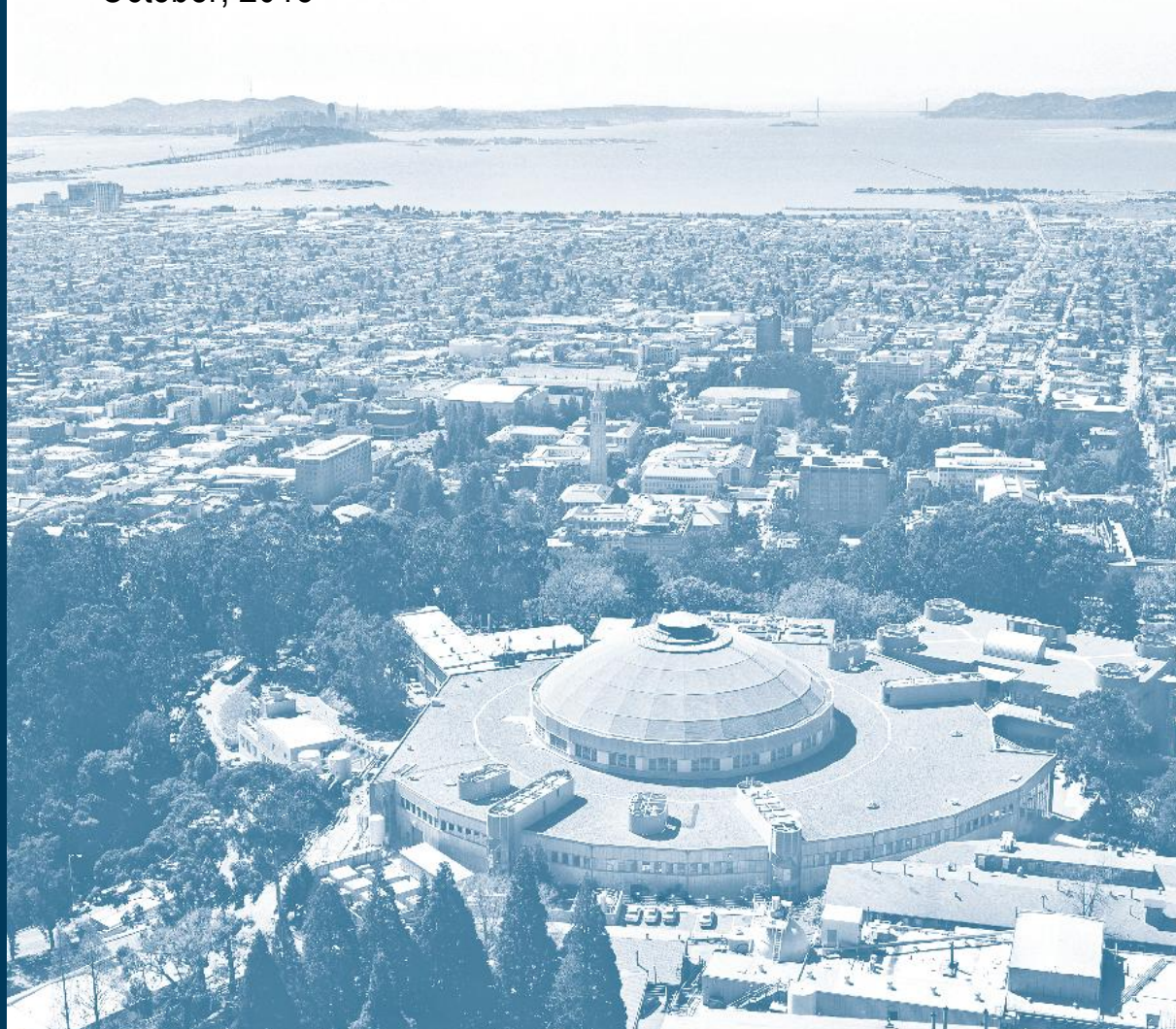

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The United States Federal Energy Management Program Lighting Energy Efficiency 2017 Update and Impacts

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Abstract

Lighting consumes a great deal of electrical energy in buildings, and the U.S. federal government is the largest single energy consumer in the United States. Therefore, the way that the U.S. federal government manages its lighting energy use is of great importance. One important way that energy use is managed is through Federal Energy Management Program (FEMP) energy efficiency requirements. However, there is not much literature on how these requirements are set and how to value the resulting savings. This paper documents the methodology used to develop these for the 2017 FEMP lighting update. A methodology for calculating the total benefits is presented that goes beyond site energy saved, and includes full fuel cycle energy savings, energy cost savings, emissions offset and monetized emissions costs. The results show total benefits of $33 million USD including 475 kilotons of carbon dioxide (CO_2) offset under the low compliance scenario, $104 million USD including 1,494 kilotons of CO_2 offset under the medium compliance scenario, and $217 million USD including 3,124 kilotons of CO_2 offset under the high compliance scenario.

Keywords: energy policy; energy efficiency; lighting; federal policy; appliance standards; federal energy management program.

Introduction

The federal government is the largest single energy consumer in the United States and one of its largest energy end-uses is lighting (US FEMP 2017). In 2016, lighting applications in U.S. commercial buildings consumed 500 trillion kilowatt-hours of electricity, or 0.50 quads (EIA 2017), approximately 5% of which was from the federal sector. This corresponds to approximately $45 billion in annually in energy costs.[3] Although this value is already substantial, it only includes electrical energy directly consumed by light fixtures, also known as *luminaires.* A luminaire is a complete electrical lighting unit and may comprise of one or more lamps, a ballast, controls, mounting, or housing. Other factors, such as heat emitted by the luminaires (which may further increase energy use for space cooling) or factors associated with producing and delivering the electricity, drive further energy use and increased emissions. The magnitude of lighting energy use underscores the need to manage it effectively. Due to both its size and visibility, the U.S. federal government has the opportunity to substantially impact energy use nationally. One of the major ways that it achieves this is through the procurement requirements set forth by FEMP. Since 1975, FEMP has reduced energy use intensity[4], or EUI, in federal buildings by 47.4%, even though the number of energy-consuming devices has grown during the years since then. Although the FEMP program is impactful, outside of an occasional brief mention (Gillingham

[3] Estimated using federal electrical price of 0.09$/kWh (US FEMP 2017)

[4] *Energy use intensity* refers to the energy used per unit area, typically expressed in kilowatt-hours per square foot (kWh/ft^2).

et al. 2006) there is no literature quantifying its effectiveness or documenting its methodology in detail. There has been one study (Harris and Johnson 2000) analyzing FEMP procurement policies at a high level. However, the scope and methodology of that study are very different to this paper, as this paper focuses on the details of the lighting program and its update process, while the previous study estimated the aggregate effect of FEMP appliance energy efficiency policy for 21 appliances. Furthermore, the literature has since provided updated values for some components of the analysis, such as the level of compliance in federal procurement (Scodel and Demates 2015) and estimates of GHG emissions based on site energy use (Coughlin 2014) as discussed later in this paper.

Executive Order (EO) 13693, "Planning for Federal Sustainability in the Next Decade," issued in March 2015, outlines a number of targets and measures for federal agencies to reduce greenhouse gas (GHG) emissions, including several components targeted at reducing energy usage in buildings, which account for 39% of federal energy consumption (US FEMP 2017). The EO also reiterates existing requirements for federal buyers to procure energy-efficient products, which are products that provide the same service as their traditional counterparts but use less energy. Per this guidance, FEMP requirements for many appliance categories are those set forth by ENERGY STAR. Several categories, including many commercial categories, do not have equivalent ENERGY STAR categories. For these, FEMP sets its own efficiency requirements, roughly following similar precepts as ENERGY STAR ratings. Per these requirements, a recommended product must provide an identical or better service while achieving a certain level of performance with respect to energy efficiency. For most categories, this value is at the 75th percentile of all available models. In some cases, FEMP may set a lower guideline in order to maintain product availability or to remain technology neutral, so as to avoid unduly favoring a specific manufacturer or design. Once FEMP has identified this value and set its requirement, federal procurement staff are required to only purchase equipment that is at least as efficient as the required value. The categories covered for luminaires are exterior, industrial, fluorescent ceiling-mounted, fluorescent suspended, and commercial or industrial light-emitting diodes (LEDs).

The following sections describe the process for setting this value, as was done for the latest round of FEMP luminaire efficiency updates in 2017. This includes the data collection, sorting, and cleaning, and the rest of the process by which the data are used to develop recommended efficiency levels. An estimate of the benefits due to the updated energy efficiency requirements is presented. The benefits covered include energy savings, energy cost savings, GHG offset, and a total savings value, which includes full fuel cycle (FFC) energy cost savings and savings due to offset emissions. Note that this process is not necessarily unique to lighting in the federal government. FEMP uses similar methodologies for other products and both that and the benefits calculation procedure could be applied to other energy programs or conservation measures.

Methodology

Lighting Models Assessment

When an appropriate ENERGY STAR category does not exist or is otherwise not applicable, FEMP is required to formulate an original energy efficiency requirement. The typical target for the energy

efficiency requirements is the 75th percentile of models by efficiency. For luminaires, the primary metric is the Lighting Efficacy Ratio (LER), which is the efficacy defined in terms of lumens per watt. To identify the 75th percentile, FEMP uses two metrics.

The first metric is based on the Number of Models (NOM) approach, in which FEMP collects performance data on as many products within the category as possible and sets the efficiency requirement such that the most efficient 25% of models would qualify. For example, if there were 100 models in a dataset, the requirement would be set at a point that allows the 25 most efficient products to comply.

The second is the Range of Performance (ROP) approach, in which FEMP sets the efficiency requirement based on the difference between the least and most efficient models in a dataset. It is represented by the following formula in Equation 1:

(1) $E_{ROP} \geq E_{min} + [0.25 \times (E_{max} - E_{min})]$

where:

E_{ROP} = the efficiency requirement based on Range of Performance

E_{min} = the performance of the least efficient product

E_{max} = the performance of the most efficient product

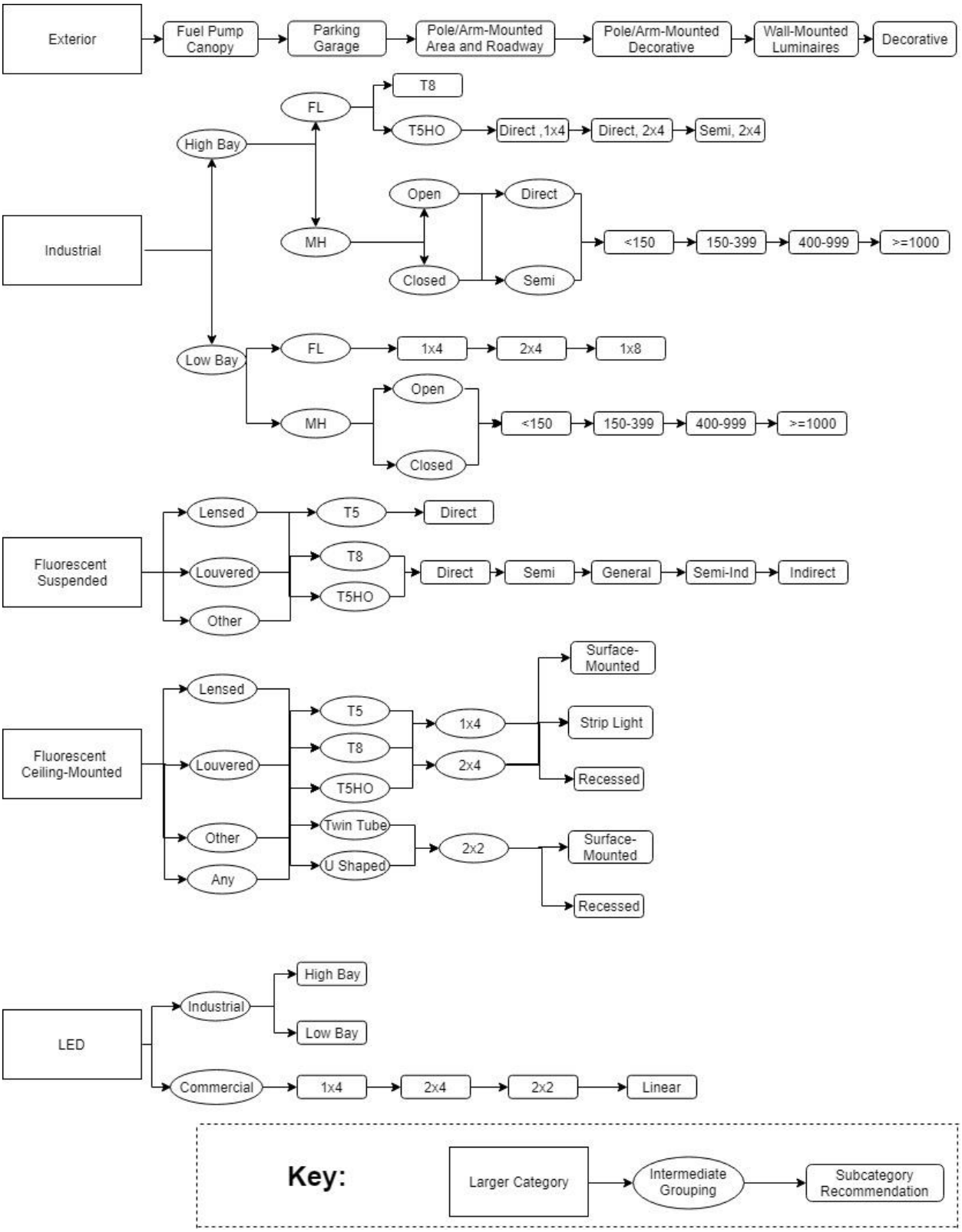
In addition to these metrics, FEMP also sets its requirements such that a particular manufacturer is not favored. To implement this, FEMP requires that models from a minimum of three manufacturers are represented. The last factor in setting the requirement is that the models represent a stable distribution, meaning that additional models in the subcategory are unlikely to affect the value substantially. While this is typically done via manually inspecting the data, a typical rule of thumb is the presence of 30 models.

Both the NOM and ROP approaches require high-quality performance data to be accurate. A database was assembled by gathering existing databases and manufacturer literature. In the 2017 lighting update, one additional existing database associated with the lighting simulation and design tool AGi32 was used, as in many cases it was more comprehensive and more frequently updated than manufacturer literature. The final assembled database was cleaned and sorted according to FEMP subcategories, which are formed based on application, capacity, and technology type. Luminaires that did not include enough information to definitively identify them as a particular subcategory were not used.

Figure 1 below provides a visual representation of the FEMP lighting categories and subcategories. The rectangles on the far left represent the largest categories. Ovals represent intermediate groupings. The rounded-edge rectangles on the far right represent the final subcategories for which requirements are issued. The final database that was used to form the requirements consisted of approximately 65,000 luminaire models which were sorted into 117 subcategories. It may be possible to identify additional models that should be included in order to form a larger final database and

improve the market characterization to be as accurate as possible. However, in almost all subcategories there are more than enough data to form a stable distribution. The exterior category includes all lighting technology types, while the other categories specify the technology type.

Figure 1: FEMP Lighting Categories



Legend:

FL: Fluorescent; MH: Metal Halide

T8, T5HO, T5, Twin Tube, U Shaped: Fluorescent lamp type

Direct, Semi, General, Semi-Ind, Indirect: Distribution pattern

1x4, 2x4, 2x2: Troffer size

Lensed, Louvered, Other: Optical Element

Open, Closed: MH luminaire type

<150, 140-399, 400-999, >1000: MH lamp capacity (watts)

Energy Use and Emissions Reductions Impacts

The total energy use is calculated using the energy use per luminaire and the total number of luminaires used in the federal sector. The approach for calculating the total federal lighting sector in terms of the number of luminaires is similar to the methodology from Lawrence Berkeley National Laboratory (LBNL) which was applied to several appliance categories (Fujita and Taylor 2012). First, the total square footage of federal buildings subject to FEMP regulations is gathered from the most recent federal annual energy report (US FEMP 2017). Residential and commercial square footage is disaggregated based on building type. Next, the product density is calculated in terms of square footage per luminaire. Finally, the shipment modifier represents the fraction of the stock that applies to a given subcategory. These values are combined to form the stock, as in Equation 2. This value is further modified by the compliance ratio, which is the portion of the federal sector which in practice follows the requirements.

(2) $Stock_{subcategory} = Floor\ Space * Product\ Density * Shipment\ Modifier_{subcategory}$

where:

Stock = Number of luminaires in the federal sector

Floor Space = Floor space in the federal sector (1,000 ft^2)

Product Density = Number of units per unit area (units/1,000 ft^2)

Shipments Modifier = Disaggregates the shipments per FEMP's subcategories. This disaggregation is based on the model database as well as the floor space designations, such as commercial or residential.

The 2015 Lighting Market Characterization (LMC) (Navigant 2017) provides several important lighting statistics for the United States. These include the installed stock, associated floor area, and daily operating hours (all broken down by area), including residential, commercial, industrial, and outdoor. The 2015 LMC showed a relatively small difference between luminaire density in residential and commercial buildings at 24.4 and 24.3 lamps per 1,000 ft^2, respectively, so for simplicity only the commercial value is used. The data shows approximately 1.15 lamps per luminaire leading to a value of approximately 21.7 luminaires/1,000 sqft. To avoid overestimating savings, this value was rounded to a value of 20 luminaires/1,000 sqft.

The analysis period is two years, as FEMP lighting requirements are updated every two years. The annual shipments value is calculated by applying the estimated failure rate to the aforementioned

stock. Since only two years of shipments are considered in this analysis, a single value is used for each year, as opposed to estimating a future shipment. The lifetime is estimated at 15 years, consistent with FEMP requirements (U.S. FEMP 2017),[5,6,7,8] and the operating hours values are from LMC 2015. The baseline efficiency distribution assumes a frozen efficiency distribution compared to the current year, meaning the efficacy of luminaires remains constant in future years. The baseline efficiency distribution only refers to federal procurement. Finally, the database reports unit information necessary to calculate the energy use, including lamps per luminaire, lamp power, luminaire power, and LER value. Combining these values as per the equations below, the baseline energy use can be calculated, as can the energy use in the presence of the increased efficiency values. Applying the energy use to the federal electricity cost (US FEMP 2017) gives the energy cost. Equations 3 through 6 reflect this process.

(3) $Annual\ Energy\ Use = Luminaire\ Power * Daily\ Operating\ Hours * 365$

(4) $Lifetime\ Energy\ Use = Annual\ Energy\ Use * Lifetime$

(5) $Energy\ Savings = Annual\ Shipments * (Lifetime\ Energy\ Use_{2015} - Lifetime\ Energy\ Use_{2017})$

(6) $Lifetime\ Energy\ Cost\ = Annual\ Energy\ Use * Federal\ Electricity\ Price * Federal\ UPV$

where:

Luminaire Power is from the lighting database assembled for this project

Daily Operating Hours is from LMC 2015

Annual Shipments is estimated from federal floorspace and product density

Federal Electricity Price is from the annual FEMP report

Federal UPV is the federal discount rate, from the National Institute for Standards and Technology (NIST) report (Lavappa, Kneifel, and O'Rear 2017)

Another factor in estimating the impact of FEMP requirements is the compliance ratio. This refers to the portion of federally procured luminaires that comply with the new requirements. In 2008, Alliance to Save Energy (ASE) reviewed federal procurement solicitations (Capanna, Devranoglu, and Loper 2008). This report found that 7% of solicitations were compliant with FEMP requirements. A follow-up study in 2011 by ASE revealed that 46% of solicitations mentioned ENERGY STAR or FEMP requirements, while only 24% mentioned the specific applicable requirement for the product. A 2015

[5] Purchasing Energy-Efficient Suspended Fluorescent Luminaires. EERE. https://energy.gov/eere/femp/purchasing-energy-efficient-suspended-fluorescent-luminaires
[6] Purchasing Energy-Efficient Exterior Lighting. EERE. https://energy.gov/eere/femp/purchasing-energy-efficient-exterior-lighting
[7] Purchasing Energy-Efficient Ceiling-Mounted Fluorescent Luminaires. EERE. https://energy.gov/eere/femp/purchasing-energy-efficient-ceiling-mounted-fluorescent-luminaires
[8] Purchasing Energy-Efficient Industrial Luminaires (High/Low Bay). EERE. https://energy.gov/eere/femp/purchasing-energy-efficient-industrial-luminaires-highlow-bay

study from LBNL further analyzed these values and found an effective compliance for lighting of 22% and an overall FEMP category effective compliance rate of 30% (Scodel and Demates 2015). These values form the basis for the compliance scenarios, which are Low (7%, Capanna, Devranoglu, and Loper 2008), Medium (22%, Scodel and Demates 2015), High (46%, Siciliano 2011) and Full (100%). These percentages are applied to the estimated shipments to calculate the shipments affected by the requirements.

To most accurately quantify the impact of the energy savings FEMP lighting requirement update, it is important to consider not only the primary energy and energy cost savings, but also other factors, including accounting for the FFC and GHG emissions. In general, the FFC refers to the energy consumed in extracting, processing, and transporting primary fuels (i.e., coal, natural gas, petroleum fuels), and thus presents a more complete picture of the impacts of energy conservation standards. In the context of lighting, FFC refers primarily to any transmission or distribution losses in the electric grid, as well as electrical energy used upstream. Regarding GHG emissions, the types of GHGs covered are CO_2, nitrogen oxides (NO_x), methane (CH_4), and nitrous oxide (N_2O) associated with electricity production. These, in addition to the aforementioned, comprise the FFC in accordance with the U.S. Department of Energy's FFC Statement of Policy, 76 FR 51282 (August 18, 2011). The methodology for calculating these values is described in "Utility Sector Impacts of Reduced Electricity Demand" (Coughlin 2014). For CO_2 and NO_x, the monetary equivalents are based on the social cost of carbon (SCC), which draws from the body of literature regarding the effects of increased GHG emissions (OMB 2006; Interagency Working Group 2010, 2013). These in turn reference the DICE (Nordhaus 2008, Nordhaus 2010), FUND (Narita et al. 2010), and PAGE (Hope 2013) integrated assessment models which are the primary models cited in the literature and used in energy policy (Stanton et al. 2011, van Vuuren et al. 2009). For CH_4 and N_2O, the raw values from electricity production are converted into carbon dioxide equivalent (CO_2e) for the purposes of comparison. This is done by multiplying the physical emission units by the global warming potential (GWP) over a 100-year time horizon based on the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2013).

Results

Table 1 reports the FFC energy savings, energy cost savings, CO_2 equivalent and NO_x offset, and total benefits, which include the lifetime energy cost savings and the GHG offset monetary equivalencies. The energy savings and cost savings are calculated by comparing the energy use between the luminaires at the previous recommended level against the new level. These values are presented for each class and the total. Lighting energy efficiency requirements are updated every two years, so the benefits reflect the two years of affected shipments. Although only two years of shipments are covered by this analysis, the benefits are still substantial. The results presented in Table 1 are presented by category. For example, commercial LEDs, which are a separate FEMP product class from commercial fluorescent luminaires, are presented together. Note that these results represent estimates from actual US FEMP efficiency requirements created through the methodology documented in this paper.

Table 1: Primary Results – Energy and Cost Savings for the 2017 FEMP Lighting Update

	Energy Savings (TWh)	Energy Cost Savings (million USD)	CO_2e/NOx Offset (ktons)	Total Benefits (million 2017 USD)
Full Adoption – 100%				
Commercial – Suspended	1.38	109.8	1,961/1.5	136.3
Commercial – Ceiling Mounted	0.95	76.0	1357/1.1	94.3
Industrial	0.31	24.5	437/0.34	30.3
Exterior	2.13	170.1	3,037/2.4	211.0
Total	4.76	380.4	6,792/5.3	471.9
High – 46%				
Commercial – Suspended	0.63	50.5	902/0.71	62.7
Commercial – Ceiling Mounted	0.44	35.0	624/0.49	43.4
Industrial	0.14	11.3	201/0.16	14.0
Exterior	0.98	78.2	1,397/1.1	97.1
Total	2.19	175.0	3,124/2.44	217.1
Medium – 22%				
Commercial – Suspended	0.30	24.2	431/0.34	30.0
Commercial – Ceiling Mounted	0.21	16.7	299/0.23	20.7
Industrial	0.07	5.4	96/0.08	6.7
Exterior	0.47	37.4	668/0.52	46.4
Total	1.05	83.7	1,494/1.2	103.8
Low – 7%				
Commercial – Suspended	0.10	7.7	137/0.11	9.5
Commercial – Ceiling Mounted	0.07	5.3	95/0.07	6.6
Industrial	0.02	1.7	31/0.02	2.1
Exterior	0.15	11.9	213/0.17	14.8
Total	0.33	26.6	475/0.37	33.0

The aforementioned savings are attributable exclusively to decreased energy use due to increases in LER as the result of the new requirements. Figure 2 shows the LER improvements from the 2015 to the 2017 update by category. Note the especially large increase in the exterior category. This is due to the inclusion of LEDs in the 2017 FEMP requirements; whereas, previously, LEDs were not included. While these values are highly aggregated between luminaire types, they highlight the advance of efficiency in lighting as shown by the rapid advance of the 25th percentile in each category. A large portion of this is likely LED adoption both in the exterior category and the commercial categories. Table 2 shows the estimated energy cost savings by luminaire type. The cost savings of incorporating LEDs into the energy efficiency requirements for the exterior category is further highlighted. The savings for industrial are also higher than in either commercial category due primarily to the higher capacity in that category.

Figure 2: LER improvements 2015-2017

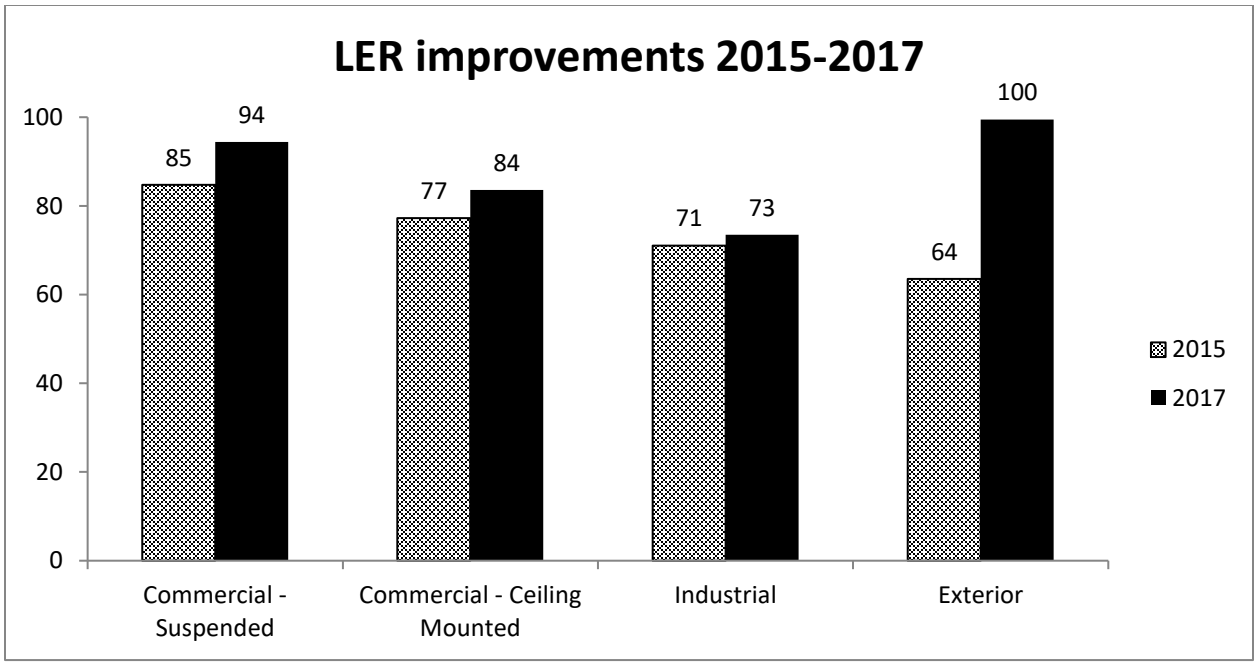


Table 2: Energy Cost Savings by Luminaire Category

	Commercial - Suspended	**Commercial – Ceiling Mounted**	**Industrial**	**Exterior**
Energy Cost Savings Per Unit (2017 USD)	36.39	22.94	50.59	327.14

Discussion

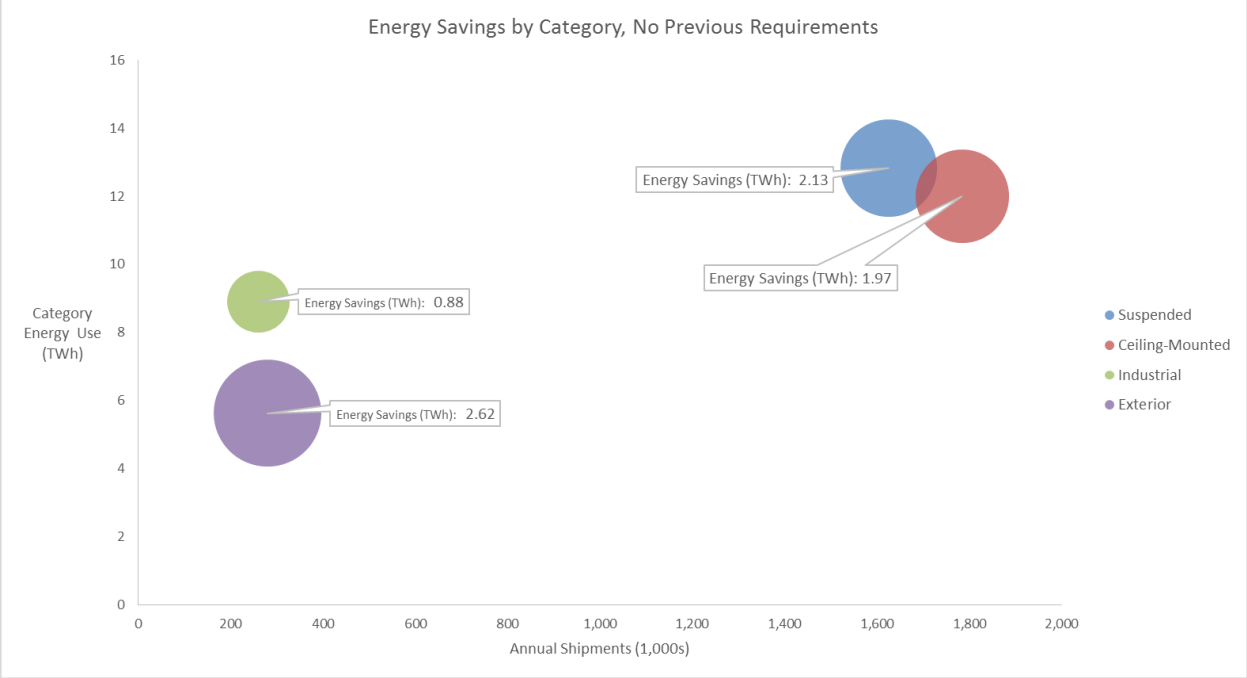
Due to the size of the federal sector, even a low compliance scenario of 7% results in total benefits of $33 million USD, as shown in Table 1. Even with such a low compliance scenario, the savings are substantial. The high compliance scenario results in $217 million USD in net benefits. Under the medium compliance scenario, which according to Scodel and Demates (2015) is the effective compliance ratio for lighting, the updated requirement results in $104 million USD of net benefits. This highlights the importance of setting and regularly updating these requirements, and shows the importance of high compliance rates for these requirements for lighting and other appliances. Due to the size and heterogeneity within each category, and the added complexity of the federal procurement system, this analysis does not take into account the potential first cost increases, which are likely far outweighed by the benefits.

The savings for the exterior lighting category is especially large because this is the first to require LEDs. The inclusion of LEDs resulted in the exterior category having the largest savings of any category,

even though it only represents 7% of luminaires covered by the FEMP requirements. While this result underscores the importance of up-to-date efficiency requirements, part of the outsize impact of exterior luminaires relative to shipments is due to exterior luminaires having the highest capacity and daily use of all of the categories.

While the savings presented in Table 1 are substantial, they are for the 2017 update only. In a scenario where previous FEMP efficiency requirements do not exist, the potential savings are likely even more substantial. Figure 3 is intended to show the benefits of implementing such an energy efficiency program where one previously did not exist. Assuming that in such a scenario the efficacy of the average luminaire that would have been purchased is the average luminaire in the model database, Figure 3 shows the potential savings under the same assumptions and financial values as Table 1. As expected, the savings from all four categories are substantial, and represent an increase of between 23% and 184% in the case without FEMP requirements compared to the "Full Adoption", real-world case as presented in Table 1. This likely understates the benefit of efficiency requirements, as it does not take into account the effect of the requirements on the market, as the federal sector is so large. To preserve comparison with Table 1, the Exterior category was analyzed excluding LEDs. In total, implementing an energy efficiency program has the potential to save 2.76 TWh more energy than the savings for this round of FEMP. This shows the potential of implementing and maintaining energy efficiency programs, when possible.

Figure 3: Potential Savings by Category if prior FEMP requirements did not exist



Compared to other energy conservation methods these energy savings come at relatively little cost compared to other potential utility programs. As by 2025, the spending on electric and gas efficiency programs is projected to reach between $6.5 and $15.6 billion USD (Barbose et al. 2013). The effectiveness of such programs have been found to be around $0.016 - $0.033 USD/kWh (Friedrich et al. 2009). In comparison to the energy savings from these methods, the cost of implementing the FEMP energy efficiency requirement program and directing procurement to buy according to the requirements is almost negligible. For example, assuming a scenario where implementing a program such as this were to cost $500,000 USD or less, the cost for energy savings would be less than $0.0015 USD/kWh under the medium compliance scenario. This neglects the increased first-cost of the luminaires, however, even conservatively considering a first cost increase of $75 per luminaire, such a program is still cost effective at $0.039 USD/kWh.

Another factor not captured in this analysis is the effect on manufacturers. The U.S. federal sector has substantial purchasing power, and so manufacturers may be affected by FEMP requirements. While a shift in the market may incur some costs to some manufacturers, it also has the potential to make U.S. products more competitive in the global marketplace as costs for more efficient products are driven down and technological innovation is incentivized. Additionally, it has been shown that energy efficiency programs can create jobs (Wei et al. 2009), an economic benefit not captured in this analysis.

This analysis can be used as a framework to further assess the benefits of similar efficiency requirement increases for other appliances, as FEMP issues requirements using this methodology for several other appliance categories also not covered by ENERGY STAR. It may also be useful as a model or for comparison with efficiency programs in other contexts, such as municipalities, utilities, or smaller-scale public or private entities. This type of holistic analysis of energy savings and emissions offset can even be applied to energy conservation measures implemented in an individual building, and could thus be of interest to building engineers, architects, building managers, or similar energy professionals to more accurately value projects. Finally, documenting the process and sharing it with the greater community invites comparisons and potential improvement.

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