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Forrestal Tubular LED Demonstration Project: Lessons Learned

June 2017

MA Myer

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Richland, Washington 99352

Acronyms and Abbreviations

AC	alternating current
BAA	Buy American Act
CBP	US Customs & Border Protection
DC	direct current
DLC	DesignLights Consortium
DOE	U.S. Department of Energy
ECM	energy conservation measure
ESCO	energy service company
ESPC	energy service performance contract
FEMP	Federal Energy Management Program
GHG	greenhouse gas
GSA	U.S. General Services Administration
HQ	Headquarters
IES	Illuminating Engineering Society of North America
IGA	investment-grade audit
LED	light-emitting diode
M&V	measurement and verification
NOO	notice of opportunity
PNNL	Pacific Northwest National Laboratory
RP	Recommended Practice
SSL	solid-state lighting
VDT	visual display terminal
TAA	Trade Agreements Act
TLED	tubular LED
UFC	Unified Facilities Criteria
VEIC	Vermont Energy Investment Corporation

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Executive Summary

The relighting of the James V. Forrestal Building was officially completed in January 2017. The project consisted of replacing the existing fluorescent lamps with tubular LEDs (TLEDs), and was completed as part of the Federal Energy Management Program (FEMP) ENABLE process.

As a result of the relighting, it is expected that the annual energy savings will be roughly 2.4 million kWh. Of that energy savings 2.1 million kWh is directly attributed to the new lighting and 300,000 kWh is related to a reduction in the HVAC usage. Fluorescent lamps were replaced with TLEDs that can operate directly on the existing fluorescent ballast (also known as UL Type A TLEDs).

The advantage of UL Type A TLEDs is a reduced first cost because of limited labor cost related to modifying the light fixture. The nominal 32 W fluorescent lamps were replaced with nominal 12 W TLEDs.[1] Roughly 35,000 fixtures (mostly containing one lamp) were retrofitted with the TLEDs. No additional lighting controls were installed during the retrofit compared to any spaces that utilized controls before the retrofit.

Although the retrofit was a success in terms of meeting ROI targets, saving energy, and completing the project on time, market and technical issues were encountered during the project. This document discusses the market and technical issues as well as proposes potential solutions for those issues. Major market and technical issues included:

1. FEMP ENABLE announcements are bid on by perspective entities. However, those entities that do not win the bid do not always know the reason (or even a high-level reason) for losing the bid. Although not an issue on this project, the energy services company (ESCO) that won the bid stated that in previous lost bids they often did not know high-level reasons for the missed opportunity. Having this information might enable ESCOs as a whole to respond with higher quality bids in the future.

2. Federal entities lack information specifically related to TLEDs. Currently, there is no FEMP-designated category for TLEDs. Lighting information touches on TLEDs, but no TLED-focused documents and guidance exist as a federal resource.

3. Need for in-depth technical information from third parties is desired on the part of both of FEMP ENABLE and the ESCO. This was not an issue on this project because of a special circumstance of having a technical expert as part of the team, but both the ESCO and FEMP ENABLE project facilitator recognized the benefits of having the technical resource.

4. Buy American Act is a provision that equipment is either finally constructed or a large-portion of the equipment is manufactured in the country. However, finding suitable products that are BAA-compliant can be a challenge. There are also certain provisions related to BAA that need to be considered when selecting potential equipment.

[1] Actual power draw of the fluorescent lamp is less than the nominal 32 W when operated on a normal ballast factor (0.88) which is common in most applications. In contrast, because of interactions between the TLED and the ballast, the actual power draw is actually greater than the nominal power value.

5. Access is limited in federal buildings and contractors having the necessary badging can expedite projects.

6. Financing is an essential component to the FEMP ENABLE process. However, the work by the financiers is roughly the same amount for both small and large projects. As a result, securing financiers can be a problem for certain projects.

7. Illuminance is the amount of light falling on the surface. Current federal guidance and requirements refer to the metric but do not provide detailed methods for measurement nor explicit information about the desired values.

8. End of life for LEDs is different than other light sources. TLEDs with integral drivers will degrade slowly in light output until the TLED no longer operates. However, this information not readily presented in most lighting guidance for federal entities.

9. Flicker is a sensation that is perceptible when the light is modulating in output. Flicker is not inherent to LEDs, but some spaces within Forrestal had flickering LED lights and that problem had to be remedied during the process by replacing the ballast and wiring configuration.

Throughout this document, these market and technical issues are discussed along with potential solutions.

1.0 Project Background

The Federal Energy Management Program (FEMP) is committed to providing government agencies with the information, tools, and assistance needed to effectively manage energy use. With more than 230,000 energy-using buildings and structures and 600,000 road vehicles, the federal government is our nation's largest energy consumer (DOE 2014a). This report presents the lessons learned from FEMP's involvement in a large lighting retrofit at the U.S. Department of Energy (DOE) Forrestal Building in Washington D.C. in 2016. Potential solutions based on lessons learned from this project, which should be considered for future improved implementation of this technology are presented.

The purpose of the retrofit was to replace the more energy-consuming fluorescent lamps with leading-edge and relatively untested-in-the-field direct-replacement tubular light-emitting diode (TLED) lamps that operate on the fluorescent ballasts (as a cost savings) within large selected areas of the Forrestal Building.

In developing this lessons learned report, Michael Myer from Pacific Northwest National Laboratory's (PNNL) drew from his experiences working with the project team as a FEMP technical advisor to the lighting retrofit project. Key project participants were interviewed including;

- FEMP ENABLE project facilitator[2] – Mike Holda (who retired from Lawrence Berkeley National Laboratory during the project)
- ADI Energy – John Rizzo, CEO of ADI Energy, the energy service company (ESCO) selected to perform the energy service performance contract
- DOE Headquarters (HQ) facilities staff – Justin Lieu, project manager.

In its endeavor to make federal buildings more energy efficient, Congress passed legislation to provide energy reduction targets for federal agencies (Congress 2007). Federal buildings are required to decrease energy use by 30% in 2015 compared to 2005; an additional 2.5% annual reduction in energy use is mandated from 2015 until 2025. Additional legislation and Executive Orders provide energy and greenhouse gas (GHG) reduction goals for specific federal agencies.

Lighting use constitutes about approximately 15 – 20% of the total source electricity consumption in commercial buildings (actual value depends on the age of the building); therefore, the use of lighting-related energy conservation measures has the potential to help significantly in meeting the above stated legislative targets. This project resulted in an energy savings of roughly 50% of the lighting energy use in the space.

[2] Energy Savings Performance Contract (ESPC) ENABLE is designed to permit a standardized and streamlined procurement process for small federal projects to install energy conservation measures (ECMs) in 6 months or less. https://energy.gov/eere/femp/energy-savings-performance-contract-enable-federal-projects

2.0 Project Overview

In January 2016, the Secretary of Energy directed the DOE Office of Management, Office of Logistics and Facilities Operations to demonstrate efficient and innovative lighting technologies at the DOE Forrestal Building in Washington D.C. The Secretary of Energy specifically suggested the use of solid-state lighting (i.e., LEDs) because of DOE-sponsored research that shows their energy and cost savings potential.

Because of PNNL's leadership in lighting technology research, FEMP requested their technical expertise to assess DOE's needs, analyze appropriate technologies for these needs, interact with the industry vendors, and to analyze and provide recommended lessons learned.

From the start, several key variables affected project decisions, including:

- *Short project timeline*. DOE requested that the analysis be completed and the lighting installed before transition between Secretaries of Energy in January 2017.
- *Lighting technology identified*. Per DOE, the lighting technology requested was solid-state lighting, specifically LEDs.
- *Projected building life 10 years*. The Forrestal Building, with construction completed in 1969 and with no historic architectural features, is slated for potential replacement in approximately 10 years. Therefore, a payback of less than 10 years was desired.
- *Over lighting*. The Forrestal is over lighted, which results from the significant quantity of fixtures. In contrast, newer buildings or newly constructed buildings would have fewer light fixtures. As a result, the solution needed to consider fewer lumens for energy savings and not assume a 1 to 1 replacement of lamps.

The over-lighting issue and over technology issues are described in more detail in the next subsections.

2.1 Decision Technology Overview

PNNL presented the DOE Forrestal facilities team with a range of options for implementing replacement of fluorescent lighting with LEDs in specific areas of Forrestal (see Table 1).

Table 1. Original Demonstration Project Technology Options

Option	Description	Light Source	Issues/Technical Risk	Advantage	≈ Energy Savings	First Cost
1	Reduced wattage fluorescent	FL	Does not meet Sec.'s requests for savings for LED source	Very low cost – easiest solution	20%	₡
2	In-Line Ballast TLED	LED	Ballast failure, may not dim, TLED life /	Low labor and material cost	30 – 40%	$

Option	Description	Light Source	Issues/Technical Risk	Advantage	≈ Energy Savings	First Cost
	(UL Type A TLED)		performance, safety			
3	Line Voltage TLEDs (UL Type B or C TLED)	LED	Potential dimming and other control limitations	Avoids many potential issues with ballasts	30 – 50%	$$
4	Retrofit Kit	LED	Not considered cost effective for this project	Allows for energy savings as well as potential controls	60%	$$$
5	New Luminaires	LED	Not considered cost effective for this project	Maximum energy savings and potential non-energy features	30 – 60%	$$$$

This lessons learned report will not provide an in-depth review of the options provided to DOE facilities other than the information in Table 1. However, FEMP recently published a factsheet on retrofitting troffers that provides a detailed analysis of the options provide in Table 1.[3] The relighting project was constrained by two time requirements: 1) a completion date before January 19, 2017; and 2) a building life projected for 10 years.

2.2 Summary of Demonstration Project Timeline

Table 2 outlines the major events of the TLED demonstration project at the Forrestal Building. Early in the project, it was determined that the project be an Energy Savings Performance Contract (ESPC) ENABLE project. ESPC ENABLE uses a set of pre-established procurement and technical tools to administer the project. The ESPC involves a contract and guaranteed energy savings from a third-party ESCO. The timeline was a key driver to this project because the overall task had to be completed by January 19, 2017. Both the ESCO and the FEMP ENABLE project facilitator stated that the compressed timeline benefited the project. Other projects without an overarching mandate deadline can stall and the funding can shift, putting the project into jeopardy. In contrast, the finite deadline driven by senior management helped the project.

Table 2. Event Timeline for TLED Demonstration Project

Date	Event
December 2015	Secretary of Energy makes a request to demonstrate LEDs in the DOE Forrestal Building.
December 2015	DOE HQ staff reaches out to PNNL (because of PNNL's expertise in lighting research and PNNL's Solid-State Lighting Lab). FEMP supports PNNL in this role.
February 2016	PNNL, on behalf of FEMP, presents DOE with technical and cost options. Two project drivers are the 10-year or less life of the project and the request to have the work completed before the

[3] LED Retrofit Kit, TLEDs, and Lighting Controls: An Application Guide. DOE/EE 1544, PNNL-SA-123952. Available at https://energy.gov/eere/femp/downloads/led-retrofit-kits-tleds-and-lighting-controls-application-guide

Date	Event
	Secretary of Energy's tenure ended in January 2017.
March 2016	PNNL develops a specification for TLEDs to be included in a notice for opportunity (NOO). The technical specification included requirements that the TLEDs had to be Buy American Act and other technical requirements.
March 2006	NOO is issued. Companies bid on the NOO (based on experience and cost) for completing the demonstration project
April 2016	The ESCO is selected as the project contractor. With input from PNNL and ESCO, DOE selects Philips as the TLED manufacturer for the project.
May 2016	Philips and ESCO sign contracts to complete the project.
June 2016	PNNL addresses potential questions such as flicker and illuminance levels.
October 2016	ESCO starts the installation of Philips TLEDs in light fixtures.
November 2016	Installation continues.
December 2016	Installation continues and a punch list of items is addressed.
January 2017	Installation complete. Punch list items are addressed and the project is officially closed out.

2.3 Product Selection & ESCO Selection Process

The notice of opportunity (NOO) resulted in seven responses, a high response rate according to the FEMP ENABLE project facilitator. The FEMP ENABLE project facilitator attributed the number and quality of the responses to the NOO being both clear and an attractive project.

The DOE facility staff had three reviewers individually review the responses to the NOO from the different ESCOs. The reviewers each used a quantitative 1–5 scale to evaluate the bids from the ESCOs in relation to the NOO. Once the individual reviews were completed, DOE staff members met and finalized the ESCO selection.

2.4 Measurements and Verification / Results

The FEMP ENABLE has specific requirements and protocols for the measurement and verification (M&V) process for lighting.[4] The lighting technology is installed in a small quantity and both pre- and post-measurements are taken in quick successive order. Once the measurements are taken, they are reconciled and extrapolated across the facility. The ESPC is designed for M&V to be efficient and simple. FEMP specifies the protocol for M&V. Statistical measures are included in the FEMP M&V plan and as a result, limited quantities of equipment need to be measured. If lighting controls will be deployed as part of the energy conservation measure, then data loggers are used to estimate the benefit of the controls. Although lighting controls were initially discussed for this project, they were not deployed.

[4] https://energy.gov/eere/femp/downloads/espc-enable-measurement-and-verification-protocol

3.0 Lessons Learned & Potential Solutions

The TLED Forrestal Building demonstration project added to the overall knowledge of the use of TLEDs as replacements for fluorescent lamps in Federal spaces. Specifically, PNNL and the ESCO identified several key lessons learned that are summarized in the following subsections.

3.1 Market Issue: FEMP ENABLE Announcements and Rationale

During the interview process, two issues related to the selection of the ESCO were discovered. The ESCO selected, ADI Energy, was not on the initial small business vendor list of companies that DOE sent the NOO. ADI Energy found out about the project from FEMP staff at a conference, where the project was discussed. Building a list of small companies to distribute NOOs is an ongoing responsibility of FEMP.

Secondly, the ESCO brought up the lack of consistent feedback provided to the non-selected bidders. The ESCO is experienced in the FEMP ENABLE process and has bid on several projects. In other past projects (that they did not win), the ESCO did not received feedback on the selection rational. The ESCO stressed that in terms of the investment-grade audit (IGA), the ESCO has been informed post selection of his bid being high or low. However, his feeling is that the total cost of the IGA is absorbed into the project and therefore moot. In the initial stages of the FEMP ENABLE process, the ECSO is assuming the risk in the IGA until a project is awarded. Beyond this feedback from the selected ESCO, it is not known what feedback was provided to the non-selected ECSOs for the Forrestal TLED project.

3.1.1 Solution: Feedback & Information to Bidders

In order to receive better bids (and thus ideally better projects), limited but specific feedback to the non-selected ESCOs is recommended. The first issue of the ESCO not initially receiving the NOO has limited solutions. FEMP currently maintains an ESCO list[5]. In the current (April 2017) list of ESCOs, ADI is listed. Failure to inform ADI (or other ESCOs) appears to have been an oversite.

3.2 Market Issue: Lack of Technical Information

FEMP has FEMP-designated product specifications for various lighting technologies including: exterior lighting, fluorescent ballasts, fluorescent lamps, fluorescent luminaires (ceiling mounted and suspended), industrial lighting, LED luminaires (commercial and industrial), light bulbs, light fixtures (residential), light fixtures/luminaires (commercial), but not TLEDs.[6]

PNNL played a vital role on this project by providing technical information to DOE, the contractor, and DOE Facilities staff. The FEMP ENABLE point of contact and ESCO both commented on the benefit of having a lighting expert detailed to the team—specifically commenting on their lack of technical lighting expertise and need for guidance.

[5] https://energy.gov/eere/downloads/department-energy-qualified-list-energy-service-companies
[6] https://energy.gov/eere/femp/find-product-categories-covered-efficiency-programs

TLED technology has been rapidly changing and improving over the past few years, sometimes outpacing information on product performance and guidance on its' use. This can lead to a number of challenges, including differences in opinions across agencies regarding a technology's readiness. For example, the version of US General Services Administration (GSA) P100 (2016)[7] guidance in effect at the time of the Forrestal project stated in section 6.3.2.2, Luminaires, "LED lamps must not be retrofitted into existing luminaires." Although the directive from GSA did not allow TLEDs, the Forrestal building is owned by GSA and is operated by DOE, and DOE had a differing view on the readiness of TLEDs. DOE wanted to apply them in the Forrestal project, and as a result of this unique relationship, a Memorandum of Understanding between DOE and GSA was completed allowing the installation of UL Type A TLEDs in the Forrestal building. Additionally, GSA's Green Proving Ground program examined a somewhat similar TLED technology overlapping the time period of the Forrestal relighting.[8] GSA was experimenting with UL Type C TLEDs that utilize an external driver and require some fixture rewiring.

After this project began, the Department of Defense released a revised version of the Unified Facilities Criteria (UFC), 3-530-01 *Interior and Exterior Lighting and Controls*. UFC is updated in an as needed-basis and was updated three times in 2016 with each update mostly focused on TLEDs. UFC 3-530-01 (June 2016) ultimately contained a specification for UL Type A TLEDs that could be used across the military branches.

Since the completion of the Forrestal project and the development of this Lessons Learned document, GSA released a revised version of P100 (April 2017).[9] This revised version of P100 contains a revised version of section 6.3.2.2, Luminaires that allows for LED lamps (TLEDs) and then provides the requirements for the lamps. Although there is overlap between the UFC TLED specification, new GSA P100 TLED specification, and the TLED specification for Forrestal, three issues were identified during this demonstration project:

1. Staff in different Federal agencies may not be aware of the different specifications or understand key features of the specifications;

2. Where there is not overlap between the Forrestal TLED specification, the UFC TLED specification, and GSA P100 TLED specification, (as well as other TLED specifications available within the lighting industry), the differing or lacking requirements may cause uncertainty or confusion for staff not trained in lighting from identifying ideal equipment.

3. Although specifications exist, finding applicable products can be a significant challenge (see Section 3.3).

3.2.1 Solution: TLED Specification and Information

Clear technical specifications and information as well as clearly defined and articulated policy related to TLEDs in the federal sector is needed. FEMP recently completed an 8-page guide, *LED Retrofit Kits, TLEDs, and Lighting Controls: An Application Guide* (DOE/EE 1544, PNNL-SA-12952). However, this

[7] https://www.gsa.gov/portal/category/21048
[8] https://www.gsa.gov/portal/mediaId/150362/fileName/GSA_GPG_Linear_LED_Retrofit_Assessment-508.action
[9] https://www.gsa.gov/portal/content/104821

Best Practices is limited in the amount of guidance provided related to TLEDs, because it addresses other lighting as well. Recently, GSA P100 (April 2017) was published allowing retrofit LED lamps. However, interest in TLED technology is increasing and other FEMP ENABLE projects have inquired (informally to PNNL) about using TLEDs. The existing Forrestal TLED specification should be refined, and more application information and resources should be developed related to TLEDs. Also, although LED retrofit kits are not part of this project, they are a good alternative to TLEDs and should be considered for future projects.

3.3 Market Issue: Need for Up-Front and In-Depth Product and Building Review

Beyond having a suitable technical specification, multiple challenges occurred related to products sourcing. According to the FEMP ENABLE project facilitator, the customer may rely on the ESCO to select the product. However, in some cases, as with Forrestal, the federal agency can pre-select the technology or the project team may make recommendations.

By having a third-party, in this case PNNL, identify how to evaluate proposed products, the potential for a perceived "conflict of interest" was reduced, according to the ESCO. Additionally, with LED lighting technology moving so fast and so many new products and manufacturers, PNNL's expertise was a valuable resource to the ESCO and project team. In this project, PNNL provided the ESCO with a list of approximately 10 manufacturers of products that met the TLED specification. PNNL also provided assistance in reviewing the products proposed to DOE by the ESCO. DOE selected the final product.

LED lighting technology is in a rapid state of change, as is the federal guidance related to TLEDs. As of now, both the GSA and the UFC lighting-related guidance on TLEDs may be confusing or hard for Federal entities to understand, especially when it comes to identifying the best product for their specific site. Federal agencies such as GSA or Department of Defense that might want to use TLEDs would need to produce the TLED specification on a case by case basis. The FEMP ENABLE project facilitator identified the need for a FEMP website with technical information on applying TLEDs, and possibly more broadly for other emerging building technologies. Solution: More Technical Information

3.3.1 Solution: More Technical Information

In addition to a website with technical information, the FEMP ENABLE project facilitator acknowledged the benefits of a third-party technical resource. The ESCO also felt that other projects could benefit from a "resource bank" of third-party experts. Consideration should be given to developing a list of available third-party experts and including them as part of the project team.

The FEMP webpage on solid-state lighting (SSL) solutions[10] provides information on interior lighting, exterior lighting, sensors, measurement and verification, and other information.

Within the applicable FEMP lighting webpages (FEMP-designated luminaires as well as the solid-state lighting resources), there is a link to LED Lighting Facts with a custom filter so users can find

[10] https://energy.gov/eere/femp/solid-state-lighting-solutions

lighting products that meet FEMP-designated levels.[11] However, if FEMP established a formal specification for TLEDs, users would still face challenges in sourcing compliant products. LED Lighting Facts no longer contains data related to TLEDs, so the standard tool that exists for other FEMP-designated products would not work for TLEDs. In developing the TLED specification for the Forrestal building, PNNL reviewed data from the DesignLights Consortium (DLC) using an ad-hoc custom search function. Currently the DLC does not have a mechanism to allow for a filter meeting FEMP (or UFC if applicable) requirements for end users to find products. One recommended solution is for FEMP to develop a template TLED specification which can be customized depending on field conditions Additionally it is recommended that FEMP in coordination with PNNL and DLC, explore development of a custom filter to allow users to find compliant products contained in the DLC database.

3.4 Market Issue: Buy American Act

The Forrestal TLED specification required the product to meet the Buy American Act (BAA) requirements for federal government purchases. However, the BAA is not always applicable and the Trade Agreements Act (TAA) allows for procurement of products from certain other countries. Under the TAA, products must be purchased from "designated countries" – including those that are part of the North American Free Trade Agreement and certain other agreements. The product selected was manufactured in Mexico, one of the countries identified in the TAA.

During the TLED selection process, the ESCO identified products by manufacturers that met the BAA requirements for consideration by DOE. However, the products were from lesser-known/less established lighting manufacturers. DOE's preferred an established manufacturer with a business history that that would support the desired warranty. This translated to a company with lighting experience offering a 7-year warranty. Many of the well-established lighting companies who have the capacity to support long warranties currently manufacture TLEDs overseas (primarily in China). China specifically does not meet either the BAA or TAA requirements. The TLED selected for Forrestal ultimately met TAA requirements.

Federal agencies find meeting BAA (or TAA) requirements for TLED procurements to be a challenge. Post completion of Forrestal the FEMP ENABLE project coordinator referred Customs & Border Protection (CBP) to PNNL for assistance in finding BAA compliant TLED products.

3.4.1 Solution: Information related to BAA

To educate federal agencies on the requirements and exceptions of the BAA as it applies to ENABLE projects that involve lighting upgrades, a limited fact sheet or webpage related to BAA (TAA and other variations) is recommended. The FEMP website provides information related to the energy efficiency requirements, but does not explicitly link to information related to BAA nor TAA.

[11] http://www.lightingfacts.com/LFPowered/FEMP

3.5 Market Issue: Access Limited in Government Buildings

Like many federal facilities, Forrestal is a secure building. The level of security at Forrestal requires a federal badge or that guests be escorted by a person with a badge. The first phase of the Forrestal relighting work took more time and had more labor costs than the later phase because of delays with the contractors entering the facility. After the contractors entered the facility, they had to be escorted around the facility by a DOE facilities staff member with an HSPD-12 badge. Contractors had to obtain security access to the building, check in through security each day, and be accompanied by DOE Facilities staff. Ultimately, the electrical subcontractor had a staff member within their organization with an HSPD-12 badge that was reassigned to the team relighting Forrestal. As a result of this team reorganization, the electrical contractor was able move efficiently through Forrestal avoiding a DOE facilities staff member from having to work 4:00 pm to 12:00 am escorting the electrical contractor.

3.5.1 Solution: Require badge/security personnel requirements in notice/contracts

To address potential security issues in other projects, the project team should meet with building or agency security to identify the specific needs for contractors working in the space. Personnel requirements (e.g., all must be U.S. citizens, HSPD-12 badge, etc.) should be included in notices or other applicable materials advertising to potential contractors. Potential contractors need to include documentation in their bid to demonstrate that the contractor can work within the space per the agency security requirements.

Building security varies by site and is typically cumbersome. Over time, familiarity is developed with the ESCO and the building security delays are reduced. It is important to account for a loss of productivity related to building security in the schedule. The FEMP ENABLE documents (NOO, Request for Proposals, etc.) should contain language in the Scope of Work / award document about gaining access to the facility.

3.6 Market Issue: Project Timeline

Timelines can affect project success. Although short timelines can create challenges to projects, they also can reduce budget uncertainty. Both the ESCO and the FEMP ENABLE project facilitator stated that the compressed timeline benefited the project. Other projects without an overarching mandate deadline can stall and the funding can shift, putting the project into jeopardy. In contrast, the finite deadline driven by senior management helped the project.

3.6.1 Solution: Where/when possible set a relatively short finite timeline

If the schedule can be set to avoid crossing fiscal years or a significant amount of work conducted within one fiscal year, this benefits the project and secures funding.

3.7 Market Issue: Financing

Two issues arose related to financing the project. One of the challenges of FEMP ENABLE projects is securing financing. Small projects (Forrestal's relighting is considered monetarily a small project) are especially hard because the amount of paperwork (level of effort) is basically the same for the financier as for a large project. The financier has to expend significant effort, which may make them apprehensive about supporting small ENABLE projects due to the added paperwork burden.

The second issue is related to third-party incentives. Originally, the incentives were $25,000 for the third-party's fiscal year 2016 and $25,000 for the third-party's fiscal year 2017 (because the Forrestal relighting project spanned two fiscal years). Later, rather than two discrete amounts, it was changed to a single amount of $50,000. Finally, the third-party organization proposed only $42,000. However, the ESCO went to the program sponsor, Vermont Energy Investment Corporation (VEIC) and after explaining that this only amounted to less than $0.002 / kWh, the ESCO was able to convince VEIC to offer the original amount of the incentive.

3.7.1 Solution: Requirements in NOO

In terms of financing, it would serve FEMP ENABLE projects well if in the bid documents the ESCO identified the names or number of financial institutions that in prior projects the ESCO worked with on those projects. Many of the bids to the NOO list projects and energy savings. If the ESCO listed the financer as well, the reviewers would be able to estimate the ESCO's relationships with financiers. Because small budget projects may not be able to easily acquire third-party financing, an ESCO that has relationships with multiple financing organizations might be a key metric in the ESCO selection.

There is no broad solution related to addressing changes to third-party financing during the project other than incorporating FEMP ENABLE guidance to properly manage the rebates. A rebate guidance document might be of assistance.

3.8 Technical Issue: Notice of Opportunity (NOO)

The Request for Quotes (RFQ) / Notice of Opportunity (NOO) is the second formal step in an ESPC ENABLE project. The FEMP ENABLE website offers templates for facilities to use to develop an RFQ/NOO. The FEMP ESPC facilitator attributed the high number of quality responses received from proposers to the NOO being very clear and the attractiveness of the project in terms of its high visibility (DOE headquarters), a single technology, and a relatively short timeline.

3.8.1 Solution: Draft a clear and quality RFQ/NOO

Federal facility managers interested in pursuing an ESPC ENABLE project should be encouraged to use the existing FEMP ESPC RFQ/NOO templates, being sure to provide clear details, examples, and minimum requirements in order to increase their chances of receiving a large number of high quality responses.

3.9 Technical Issue: Illuminance

Post installation, per the DOE facilities team, only one case was reported to PNNL of a space being "too dim;" however, DOE received more complaints of the new lighting being "too bright." In the spaces where the lighting was considered to be "too bright," DOE facilities removed the lamps in a few of the 1' x 4' fixtures reducing the light levels. Overall, LED lighting might be considered "bright" because of the intensity of the actual light-emitting materials compared to the more distributed fluorescent sources.

However, Forrestal is a typical building in terms of lighting with many 1' x 4' recessed fixtures mounted end-to-end in the ceiling. Typically 1' x 4' recessed fixtures are spaced in a grid roughly 8' x 10' in the space. As a result of the tight spacing of fixtures within Forrestal, the perception of "bright" is fair and could have been mitigated with better fixture spacing, but in a retrofit this is both costly and time consuming. Rather than physically respacing the lighting, dimming controls could have also been used to adjust to the desired light levels. However, dimming controls would have required additional wiring and other materials that would have significantly increased the cost of the project.

Illuminance was a discussion topic during the relighting of the building. The U.S. General Services Administration PBS-P100, *Facilitates Standards for the Public Buildings Service*, section 6.1, Lighting Performance Requirements, states for horizontal lighting quantity, that the illuminance[12] should meet the Illuminating Engineering Society of North America (IES) 10th Edition Lighting Handbook. The IES recommends illuminance values based on the task being performed and the age of the occupants. Beyond those parameters, space and lighting conditions might also affect lighting choices. For office applications, the IES directs use of the "reading and writing" tasks within the office facilities. The IES further directs to establish tasks and normalize to illuminance of the most important task or most common task[13]. The IES provides the full list of IES RP-1-2012 illuminance recommendations by task. These values are summarized in Table 3. Assuming that computer use is the most common task, the recommended illuminance values per the IES is **28 fc** (converted from lux and rounded from 27.6) for workers aged 25 to 65 and **55 fc** for workers over the age of 65[14]. The IES directs the designer to normalize to the most important or common task. The average values within the summary table allow for quick reference for a building like Forrestal where spaces might have different visual tasks.

[12] Illuminance is the amount of light falling on a surface.

[13] ANSI/IES RP-1-12 American National Standard Practice for Office Lighting. The IES publishes the IES Lighting Handbook (current 10th edition, published in 2010) roughly every 10 years. If a Recommended Practice (RP) is published after the handbook, the prevalent rule is that the RP supersedes the handbook. At this time, both the IES handbook and RP-1 are in agreement.

[14] Assumes a visual display terminal (VDT) CSA/ISO Type I (matte screen finish) or Type II (semi-specular screen finish) with positive polarity. This is also known as the monitors with a light background and dark text commonly used.

Table 3. Summary of IES Recommended Illuminance Values for Reading and Writing-related Tasks

Age	<25			25 – 65			>65		
Value	Lux	fc_2	fc_1	Lux	fc_2	fc_1	Lux	fc_2	fc_1
Average	147.8	14.9	13.8	295.7	29.7	27.6	591.3	59.4	55.2
Max	250.0	25.0	23.2	500.0	50.0	46.5	1000.0	100.0	92.9
Min	37.5	3.8	3.5	75.0	7.5	7.0	150.0	15.0	13.9

NOTE:
The IES specifies lighting recommendations in SI units, lux = lumen / m^2. Although within the U.S., virtually all measurements and values are measured or discussed in footcandle(s), fc = lumen/ft^2. The IES often uses the convenient conversion of 1 m^2 = 10 ft^2 to easily convert between the two units. These values are represented as fc_2. However, the true conversion is 1 m^2 = 10.76 ft^2 and represented as fc_1.

As part of the measurement and verification protocol of the FEMP ENABLE process, as well as partially satisfying U.S. GSA approval to use TLEDs in the building, illuminance measurements were completed. Table 4 depicts the illuminance values of the fluorescent baseline, selected TLED, and other TLED options considered. The measurements in Table 4 indicated as center, left, and right refer to measurements in the space. Center is directly under the light fixture and left and right indicate locations not directly in the center. The methodology employed in the illuminance measurements by GSA are not typical per lighting measurement guidance.

Table 4. Measured illuminance from ESCO Energy Savings Performance Contract Appendix A

	Average (fc)	Left (fc)	Center (fc)	Right (fc)
Fluorescent baseline	42.3	38.1	50.5	38.3
Selected TLED	31.4	28.1	37.0	29.0
TLED Option 2	35.7	33.0	40.5	33.6
TLED Option 3	30.7	27.5	35.4	29.1

The TLED option provides 25% less light than the original fluorescent system, but the initial values of the lighting system meet the IES recommendations. However, the IES recommendations are actually "maintained" values – meaning that the design team needs to account for long-term depreciation issues to accurately assess whether or not the lighting system meets IES recommendations.

3.9.1 Solution: Illuminance Guidance and Recommendations

To address illuminance measurements and guidance related to illuminance values, FEMP should provide explicit information related to illuminance measurements and recommendations by the IES. The FEMP ENABLE Measurement and Verification Protocol (DOE 2014b) lighting measurement requirements state:

> *Lighting levels as a result of the lighting equipment retrofit will not be reduced below lighting luminance levels as recommended by the IES. Lighting levels before and after the retrofit will be measured.*

Yet, the FEMP ENABLE M&V protocol does not stipulate the IES recommendations. Nor does the FEMP ENABLE M&V document provide guidance on lighting measurements. However, the FEMP SSL

Initiative webpage[15] provides a link to the FEMP Measurement and Verification of Energy Savings and Performance Advanced Lighting Controls (FEMP M&V Performance), a guidance document that provides illuminance measurement guidance.[16] This FEMP M&V Performance guidance should be cross referenced on other FEMP webpages.

3.10 Technical Issue: End of Life of LEDs

After reviewing the initial M&V results, the PNNL lighting expert indicated that although the initial (day 1 values) of the lighting from the TLEDs met IES recommendations, during the expected life of the LED system, the illuminance values would decrease below IES recommendations.

To properly address "maintained values" in LEDs, lighting designs account for depreciation factors, including dirt accumulation as well as lumen depreciation, which are the major depreciation factors that will degrade the light output of the lighting system over time. Because current offices are relatively clean, the dirt depreciation is rather limited and will only reduce the light output by roughly 5% over the time of the system. In contrast, lumen deprecation is a much larger issues, especially for LEDs.

All light sources experience lumen depreciation. LED life is defined by the number of hours until the LED system reaches a predetermined value compared to initial light output. Current guidance by the IES is to assume a lumen depreciation of L_{70} – when the system reaches 70% of the initial values. Although the IES recommends L_{70} there is some flexibility in the choice of the value. However, in the case of the product installed in Forrestal, the manufacturer rated their product in terms of L_{70} (Philips 2017).

Appling the L_{70} value to the initial illuminance values, the projected average illuminance of the selected TLED installation is expected to be **22 fc** near the end of the expected life of the TLEDs. The TLEDs are rated at 50,000 hours, which based on the estimated 3,000 annual hours of operation is roughly 17 years of operation. However, the expected end of life of the Forrestal building occurs around 2025, at which time the TLEDs will be halfway through their rated life. The projected illuminance at that time is **27 fc**. Table 5 represents the projected values at half-way through life as well as the expected end of life.

Table 5. Projected Illuminance

	Average (fc)		Left (fc)		Center (fc)		Right (fc)	
Point of Life	½ Life	EOL	½ Life	EOL	½ Life	EOL	½ Life	EOL
Fluorescent baseline	40.6	38.9	36.6	35.1	48.5	46.5	36.8	35.2
Selected TLED	26.7	22.0	23.9	19.7	31.5	25.9	24.7	20.3
TLED Option 2	30.3	25.0	28.1	23.1	34.4	28.4	28.6	23.5
TLED Option 3	26.1	21.5	23.4	19.3	30.1	24.8	24.7	20.4

NOTE: EOL = end of life

[15] https://energy.gov/eere/femp/solid-state-lighting-solutions

[16] https://energy.gov/sites/prod/files/2016/03/f30/mv_lighting_control_wireless.pdf

3.10.1 Solution: End of Life Fact Sheet

To inform federal users about LED life and light output deprecation, a fact sheet should be developed. Although numerous resources exist on the FEMP solid-state lighting webpage, characterizing / defining LED life is a detail that is not often discussed in great detail. A fact sheet could explain and provide guidance about planning for end of life and depreciation of LED sources.

3.11 Technical Issue: Flicker

A few fixtures in the project demonstrated flicker after being retrofitted with TLEDs. There were two main contributors to the flicker: 1) a fluorescent ballast designed to operate four lamps that when retrofitted operated only two TLEDs and 2) incorrect wiring of existing fixtures made during a previous lighting upgrade..

Flicker (also called temporal light artifacts) is the constant fluctuation of light output from 100% output down to a value as low as 0% output, and back up to 100%, many times per second. The visibility or perceptibility of this modulation in light output depends on the individual observer, and the frequency at which the oscillation of light output occurs. At frequencies below 100 Hz, 10% modulation may be visible or perceptible. At 100% modulation, the flicker may be visible or perceptible even at frequencies as high as 1,000 Hz or more. At higher frequencies, the flicker is not visible by looking directly at the light, but as the observer moves their eyes or head relative to the light source, the flicker is detectable through the "phantom array effect."

Virtually all humans perceive flicker when the frequency is 50 Hz and lower, some can perceive it between 50 and 100 Hz. The frequency range related to possibly inducing epilepsy occurs in the 3 to 70 Hz range. Although some flicker might be desirable in certain situations, the flicker that concerns people in lighting is when it is distracting, annoying, leads to headaches or migraines, or causes neurological reactions in populations such as persons with autism. The oscillation in light output need not be visible to create a neurological response. Factors that introduce flicker in LEDs are the electrical supply, the driver, and dimming systems as described in the following:

- The primary cause of flicker is the alternating current (AC) of the electrical system. The potential flicker frequency (120 Hz) is twice the electrical supply frequency (60 Hz). All AC-powered light sources may flicker unless the power supply (ballast or driver) is suitably designed to reduce or eliminate the perception of flicker. Incandescent lamps flicker but it is harder to notice because the thermal inertia in the metal filament means it is still emitting light during the brief time it is not powered. In contrast LEDs react quickly to electricity. When there is no electricity, there is no light, so any driver circuit that switches or dims down the LED in a power cycle can introduce flicker. As a result the lighting industry has been working to improve driver designs for LEDs as the technology has increased in market penetration.

- After the alternating current the next common cause for flicker in LEDs is the **driver**. LEDs are direct current (DC) but the electricity supplied is in the AC form. Rectifying the AC to DC conversion causes a ripple in the voltage current output from the driver to the LED. This ripple can introduce flicker. Proper driver selection can help mitigate flicker.

- **Dimming systems** also create a potential source for flicker. Certain dimmers work by modulating the time the LEDs are on and off. These dimmers combined with certain types of drivers can create flicker in the system. *Per the DOE facilities, none of the TLEDs demonstrating flicker are being used in conjunction with dimming systems.*

ENERGY STAR does not include TLEDs, but does have a flicker requirement. However, the ENERGY STAR® Lamp Specification Version 2.0 (Oct. 2016) has a flicker reporting requirement as it relates to dimming lamps.[17] It is a reporting requirement because industry has not set a threshold value nor agreed on a final metric. ENERGY STAR currently does not have a minimum value required for all lamps, The DLC, which is a group of utilities incentivizing most non-ENERGY STAR products (including TLEDs), **does not** have a flicker requirement.

The GSA April 2017 version of P100 for LED lamps retrofitted into existing luminaires does contain a flicker requirement. Per GSA P1000 section 6.3.2.2, all LED lamps retrofitted must be dimmable if a category exists within the DLC, the product must be on the DLC qualified-product list. Furthermore, P100 states in relation to flicker, "LED products must have a 'low risk' level of flicker (light modulation) of less than 5%, especially below 90 Hz operation to prevent photosensitivity-epileptic seizures as defined by IEEE standard 1789-2015LED."

Therefore, Federal entities must first find a product on the DLC qualified-product list that is dimmable. Then the Federal entities must research for themselves if the product meets the flicker requirements per GSA's P100.

3.11.1 Solution: Proper Source Selection and Paring of Equipment

To address potential questions related to flicker, a resource related to flicker and TLEDs could be developed. Although DOE's SSL program has information about flicker and the recent FEMP troffer retrofit fact sheet discusses flicker, neither of these resources provide detailed flicker information related specifically to TLEDs. Nor do the existing DOE SSL existing flicker-related documents focus on current federal requirements related to flicker.

[17] Draft 2.1 (currently in comment/review) also contains flicker testing and reporting requirements for all lamps marketed as dimmable.

4.0 References

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TLED Specifications

Appendix A

TLED Specifications

A.1 Forrestal TLED Specification

Forrestal Building

Tubular light-emitting diode (TLED) specification for ESPC Enable relighting of building.

Light Output and Efficacy

- **REQUIRED LIGHT OUTPUT:** Minimum 1,600 lumens
- **REQUIRED BARE LAMP EFFICACY:** Minimum 115 lm/W – calculated assuming ballast losses
- **REQUIRED DISTRIBUTION:** Beam angle between 120° - 160°

Warranty and Life

- **REQUIRED WARRANTY:** Minimum 7-year warranty
- **REQUIRED LUMEN DEPRECIATION:** L70 at a minimum of 60,000 hours

Color Requirements

- **REQUIRED CCT:** Provide: 4,000 K TLEDs
- **REQUIRED CRI:** 80 or greater
- **REQUIRED:** R9 must be a positive value

Electrical Requirements

- **REQUIRED TOTAL HARMONIC DISTORTION (THD):** Less than or equal to 20% at full output
- **REQUIRED POWER FACTOR:** 0.9 at full output
- **REQUIRED:** UL 1598 Type A Certification

Manufacturing Requirements

- **REQUIRED:** Comply with Buy American Act

A.2 GSA P100 (April 2017) 6.3.2.2 Luminaires

https://www.gsa.gov/portal/content/104821

All luminaires must be appropriately selected based upon the expected application. Luminaires must have a minimum luminaire efficiency of 65 percent.

Where parabolic luminaires are used, louvers must be semi-specular or diffuse finishes; specular finishes must not be used.
LED lamps must not be retrofitted into existing luminaires unless the retrofitted product meets all of the following requirements:

- UL rating is maintained for ENTIRE fixture to include UL 1598C and UL 1993.
- If LED product category is certified by the Design Lighting Consortium (DLC), it must be published on their Qualified Products website: https://www.designlights.org/
- Retrofitted lamps must be tested by a recognized Testing Laboratory in accordance with IES standards LM-79, LM-80, and TM-21
- Minimum TOTAL fixture efficacy of 100 lumens per watt (total efficacy is a combination of lamp plus driver plus ballast)
- Product MUST BE dimmable and compatible with existing lighting control systems and future daylighting technologies
- LED products must have a "low risk" level of flicker (light modulation) of less than 5%, especially below 90Hz operation to prevent photosensitivity-epileptic seizures as defined by IEEE standard 1789-2015LED
- For common office areas, LED product MUST be dimmable and compatible with existing lighting control systems and provide a path to compatibility with future daylighting technologies, or reduced power consumption by at least 50% for non-controlled fixtures
- For back office areas, electrical, mechanical, and corridors, LED products do not have to be dimmable but compatible with existing lighting control systems and reduce power consumption by at least 50%.
- Space photometrics and glare control must meet IES guidelines for tasks performed in the retrofitted spaces.
- A mock up retrofit of typical areas of the building is required to confirm the above performance requirements of lighting output suitability controllability and flicker measurements
- Minimize lamps, light sources ballasts and driver types.

A.3 DoD UFC 3-530-01 TLED Specification

2-8.4 Light Source Retrofit
https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-530-01

Light source retrofit; sometimes referred to as a direct replacement, is a system designed in the same form factor as the existing light source intended to replace the existing light source within the luminaire. An example is a linear LED lamp, sometimes referred to as tubular LED (TLED) that is a direct replacement for a linear fluorescent lamp.

As with luminaire replacement or conversion, a light source retrofit may only extend the life of deficient or substandard system. Do not use LED retrofit light sources or LED lighting modules that have been designed and constructed to be installed in existing HID or mercury vapor luminaire enclosures. LED retrofits are approved for replacement of CFL or incandescent sources (A-Type lamp replacements with Edison bases). Warning: inserting a LED retrofit in an existing luminaire may void the luminaire's warranty. \3\ Linear LED lamp retrofits are allowed /3/ with the following criteria:

1. Underwriters Laboratories (UL) \3\ 1993 /3/ Type A Certification.

2. a. Type A is designed to operate with the existing fluorescent ballast and does not require mechanical or electrical changes to the fixture. Dual Mode Lamps (UL Type A/Type B) designed to operate off the existing fluorescent ballast and line voltage are not acceptable.
3. Compatible with existing ballast type. Do not bypass or remove the ballast of the existing luminaire. \3\ If the linear LED lamps are not compatible with the existing ballast, the existing ballast may be replaced with a compatible fluorescent lamp ballast suitable for ASHRAE 90.1 compliant lighting controls. /3/
4. Be manufactured within one year of installation
5. Dimmable
6. Frosted or diffuse-optic with a minimum beam angle of 180 degrees
7. Correlated Color Temperature (CCT) of not greater than 4100K as stated on the manufacturer's data sheet
8. Color Rendering Index (CRI) of not less than 80
9. Total current Harmonic Distortion (THD) less than or equal to 20% at full and 50% output
10. Power Factor (PF) greater than or equal to 0.9 at full and 50% output
11. Minimum efficacy of 100 lumens per watt
12. Lumen depreciation greater than or equal to L70 at 40,000 hours
13. Resulting system must produce light levels equivalent to the existing system or meet the lighting levels required in the current criteria.
14. Additional submittals that must be provided:
    a. Product Data: i. IESNA LM-79, Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products Test report for each existing fixture type being retrofitted with the linear LED lamp to be provided. Test report must include a picture of the fixture tested.
    b. Warranty: i. Written five year unconditional warranty for material. Material warranty shall include replacement when more than 10% of LED sources are defective or non-starting, when the light output of the lamp drops below 70% of the initial lumens, or when there is a noticeable color shift. /1/

A.4 DesignLights Consortium

Technical Requirements V4.1
https://www.designlights.org/solid-state-lighting/qualification-requirements/technical-requirements/#/Lamps

Light Output and Efficacy

- **REQUIRED MINIMUM LIGHT OUTPUT:**
  - Bare lamp: 1,600 lumens
  - In luminaire:

        - 2 lamps:3,000 lumens
        - 3 lamps: 4,500 lumens
        - 4 lamps: 5,000 lumens
- **REQUIRED MINIMUM EFFICACY:**
    - Bare lamp: 110 lm/W
    - In luminaire: 100 lm/W

Warranty and Life

- **REQUIRED WARRANTY:** Minimum 5-year warranty

Color Requirements

- **REQUIRED CCT:** ≤ 5000 K
- **REQUIRED CRI:** ≥ 80

Electrical Requirements

- **L_{70}:** ≥ 50,000 hours
- **PRIMARY USE:**
    - UL Type A
    - UL Type B
    - UL Type A/B
    - UL Type C

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IES Illuminance Recommendations

Appendix B

IES Illuminance Recommendations

B.1 American National Standard Practice for Office Lighting

Table B.1 is an excerpt of the office lighting recommendations. The IES provides many recommendations on office spaces that include corridors, transition areas, breakrooms, conference rooms, and other spaces besides a workspace. The values in Table B.1 are specific to reading and writing tasks performed in offices and the IES directs to use these values to determine the necessary illuminance values for an office.

Table B.1. Excerpt of IES Lighting Handbook 10th Edition Table 32.2 Office Facilities Recommendations for Reading and Writing and same values as RP-1-12 Office Lighting Application Design Illuminance Recommendations – Table B1J Office and Common Applications

Task	< 25			25 - 65			> 65		
	Lux	fc_2	fc_1	Lux	fc_2	fc_1	Lux	fc_2	fc_1
Electronic Readers									
Electronic Ink	150.0	15.0	13.9	300.0	30.0	27.9	600.0	60.0	55.8
LCD or LED devices	75.0	7.5	7.0	150.0	15.0	13.9	300.0	30.0	27.9
Facsimile									
Analog	250.0	25.0	23.2	500.0	50.0	46.5	1000.0	100.0	92.9
Digital	150.0	15.0	13.9	300.0	30.0	27.9	600.0	60.0	55.8
Handwritten Work									
Pencil									
Graphite	150.0	15.0	13.9	300.0	30.0	27.9	600.0	60.0	55.8
Red	250.0	25.0	23.2	500.0	50.0	46.5	1000.0	100.0	92.9
Pen									
Black	150.0	15.0	13.9	300.0	30.0	27.9	600.0	60.0	55.8
Color	200.0	20.0	18.6	400.0	40.0	37.2	800.0	80.0	74.3
Microforms									
	37.5	3.8	3.5	75.0	7.5	7.0	150.0	15.0	13.9
Print Media									
6-pt									
Matte	250.0	25.0	23.2	500.0	50.0	46.5	1000.0	100.0	92.9
Specular	250.0	25.0	23.2	500.0	50.0	46.5	1000.0	100.0	92.9
8-pt									
Matte	150.0	15.0	13.9	300.0	30.0	27.9	600.0	60.0	55.8
Specular	150.0	15.0	13.9	300.0	30.0	27.9	600.0	60.0	55.8
12-pt									
Matte	100.0	10.0	9.3	200.0	20.0	18.6	400.0	40.0	37.2
Specular	100.0	10.0	9.3	200.0	20.0	18.6	400.0	40.0	37.2
Visual Display Terminals (computers, laptops, etc)									
CAS/ISO Types I and II									
Positive Polarity	150.0	15.0	13.9	300.0	30.0	27.9	600.0	60.0	55.8
Negative Polarity	75.0	7.5	7.0	150.0	15.0	13.9	300.0	30.0	27.9
CAS/ISO Type III									
Positive Polarity	75.0	7.5	7.0	150.0	15.0	13.9	300.0	30.0	27.9
Negative Polarity	37.5	3.8	3.5	75.0	7.5	7.0	150.0	15.0	13.9

Task	< 25			25 - 65			> 65		
	Lux	fc_2	fc_1	Lux	fc_2	fc_1	Lux	fc_2	fc_1
Xerograph									
≥8-pt type, common graphics									
Color									
Analog	250.0	25.0	23.2	500.0	50.0	46.5	1000.0	100.0	92.9
Digital	150.0	15.0	13.9	300.0	30.0	27.9	600.0	60.0	55.8
Grayscale and/or B+W print									
Analog	150.0	15.0	13.9	300.0	30.0	27.9	600.0	60.0	55.8
Digital	100.0	10.0	9.3	200.0	20.0	18.6	400.0	40.0	37.2
Summary									
Average	144.7	14.5	13.5	289.5	28.9	26.9	578.9	57.9	53.8
Max	250.0	25.0	23.2	500.0	50.0	46.5	1000.0	100.0	92.9
Min	37.5	3.8	3.5	75.0	7.5	7.0	150.0	15.0	13.9

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