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Performance of Power over Ethernet DC Distribution

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GSA's Center for Emerging Building Technologies (CEBT) and DOE's Office of Critical Minerals and Energy Innovation enable federal and commercial building owners and operators to make sound investment decisions in next-generation building technologies based on their real-world performance.

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Introduction

Executive Summary

The U.S. General Services Administration (GSA) and the U.S. Department of Energy sponsored a field and bench-scale evaluation of a Power over Ethernet (PoE) direct-current (DC) distribution lighting system at GSA's Workplace Innovation Lab (WIL) in Washington, DC, with supplemental testing at Lawrence Berkeley National Laboratory (LBNL). Cisco provided the PoE-based DC lighting and controls platform for assessment. The project topic generally examines how DC distribution and combined power-and-data networks can help move commercial buildings from today's fragmented AC-to-DC device-by-device model toward streamlined DC-centric architectures that enable granular monitoring, flexible IT-style deployment, and intelligent "plug-and-play" integration of lighting, HVAC, security, and other Internet of Things (IoT) devices.

Quantitative performance objectives focused on whole-system energy efficiency, reporting accuracy, standby power, and cost-effectiveness. Using measurement-informed modeling that compared multiple PoE configurations to several AC LED baselines, we found that the existing WIL PoE system, designed for experimental flexibility, was 9.5 percentage points less energy efficient than a representative AC LED system, primarily due to high standby losses in the switch, gateways, and drivers. However, alternative PoE architectures with port shut-off (PSO) controls and lower standby power achieved modeled system efficiencies 6.2 percentage points higher than AC. We modelled a hypothetical super-optimized PoE system to be 17.7 percentage points higher than the AC baselines. Bench tests showed that PoE switch port metering met the <5% reporting-error target above 20 W. Standby power for the existing PoE lighting system was approximately 210 W versus about 103 W for an equivalent AC system and 83 W for a hypothetical optimized PoE design. Cost analysis of the 58,000 ft² office building modelled in Stantec's report to Cisco indicated that current-generation PoE lighting can be about 6% less expensive than AC, with near-future UL924-listed PoE systems lowering total capital costs by up to 11%. We also found annual energy and maintenance costs to be lower with PoE.

Qualitative performance objectives evaluated installation, operations and maintenance (O&M), and integration with other building systems. Installation at the WIL highlighted both the opportunity to remove ~800 lb of redundant armored AC cable and the importance of early IT coordination for non-standard switches. The lighting system ultimately utilized existing network closets and did not require special ventilation or major O&M changes. From a broader buildings perspective, the PoE DC distribution platform demonstrated how moving intelligence into IT closets and delivering power and data over a common low-voltage backbone can give real estate owners circuit-level visibility, enable dedicated closets for Wi-Fi, security, and edge computing gear, and create a common "language" for building automation. By enabling per-port metering, embedded sensing, and standardized APIs, this class of DC distribution technology can support future facilities where lighting, plug loads, HVAC, and security systems are orchestrated as part of a unified IoT fabric.

Table 1. Quantitative Performance Objectives

Quantitative Objectives	What is Being Measured	What Data is Required	Results
Energy efficiency	Whole-system percent efficiency compared to an equivalent AC system ⁴	Metered data at various points and/or bench measurements of equipment. The model the WIL with existing PoE system, a typical PoE system, an optimal PoE system (to show the technology's potential), and an equivalent AC LED lighting system	Gateway-based PoE ¹ : 9.5% lower efficiency than AC Node-based PoE ² : 6.2% higher efficiency than AC Optimized PoE: 17.7% higher efficiency than AC
Reporting accuracy	Accuracy of PoE switch port metering	Bench measurement of port output power subject to a range of load	<5% error above 20W
Standby power	Standby power of a PoE-powered LED lighting system, from the breaker to the LEDs	Bench measurement of standby power in each component of PoE system. Calculate total system standby power in all three WIL models.	Standby Loss in WIL: Gateway-based PoE ¹ : 210.3 W Optimized PoE ³ : 83.3 W Equivalent AC ⁴ : 102.9 W
Return on Investment	Simple payback period compared to an equivalent AC system	Cost data per linear foot of wiring, LED drivers, and PoE switch	UL924-listed PoE systems (coming summer 2026) anticipated to cost 11.2% less than equivalent AC

1. Gateway-based PoE - designed for flexibility in supporting many types of building experiments. It uses a high-performance PoE switch with a lighting system provided by Molex.
2. Node-based PoE - uses a similar PoE switch with lighting system provided by MHT, port-shutoff capability, and slightly more optimized floor-plan layout.
3. Optimized PoE - uses a PoE switch optimized for lighting only, Node-based drivers, port-shutoff capability, and highly optimized floor-plan layout.
4. Equivalent AC - includes four 277V lighting power buses with a wireless controller and LED driver in each luminaire, along with gateways and a control computer. Derived as an average of high-performance and typical AC LED systems

Table 2. Qualitative Performance Objectives

Qualitative Objectives	What is Being Measured	What Data is Required	Results
Installation	GSA observations regarding installation process and impacts on maintenance and operations.	Semi-structured conversation(s) with onsite and/or other relevant GSA personnel	Major difference from ordinary installation was removal of significant weight in electrical BX cables Need to ensure switches are compatible with GSA network and procedures.
Operations and Maintenance			No major issues. Adds incrementally to current IT maintenance/security operations. System uses existing network closets. Bundled teleconference solution may provide value add to occupant experience. Lighting not integrated with BAS out of the box but integration potentially possible.

Background

Power over Ethernet (PoE) is a direct current (DC) power distribution standard that combines power and data onto a single cable. It has seen early adoption in applications such as office phones, networking equipment, and cameras, all of which require high data and low power. PoE offers the convenience of a single connection and cable run for both power and data.

The potential benefits of DC power distribution networks have been studied and validated in academic research. Past studies have shown through simulation that DC distribution in buildings can reduce system loss by 12% under certain conditions, namely the inclusion of ample solar generation and battery storage.¹ Another key benefit is the potential for reducing system capital cost,² as touch-safe low-voltage DC systems obviate the need for conduit and skilled electrician labor. Other benefits include power quality,³ resilience,⁴ safety, and the potential for combined power and data.

Combined power and data may apply particularly well in energy systems integration, which will be characterized by the integration and system control over connected devices ranging from lighting and plug loads to entire HVAC systems. Such system integration in existing AC buildings has been costly and relies on adding connected devices to the already-congested wireless networks. Several DC solutions propose using combined power and data through signal modulation or including separate data wires. This approach may be the most painless and secure way to develop the highly networked buildings of the future. Technologies such as PoE with a centralized power hub may simplify data collection and controls. The PoE switch monitors the power to each port, simplifying the collection of power and usage data. Usage data may ultimately empower data-driven high-level building management, planning, and operation decisions. For example, personnel with similar usage patterns can be consolidated to save on HVAC and lighting costs.

¹ <https://www.sciencedirect.com/science/article/abs/pii/S0306261917307419>

² <https://www.sciencedirect.com/science/article/abs/pii/S0306261918312339>

³ <https://www.sciencedirect.com/science/article/abs/pii/S0306261921015658>

⁴ <https://www.sciencedirect.com/science/article/abs/pii/S0306261923005822>

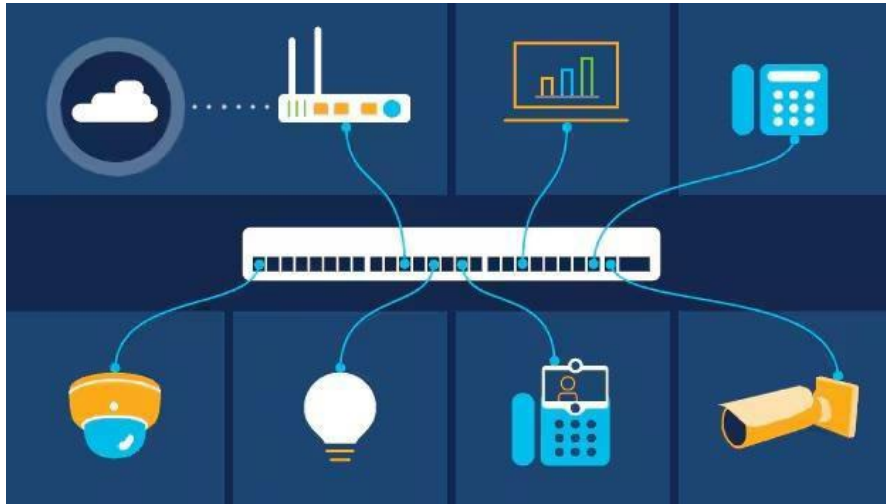


Figure 1. Sample PoE network diagram. Source: Cisco

Low-voltage DC distribution is convenient in ceiling circuits, since lighting, fans, and sensors are all low power, and electricians are not needed for installation or reconfiguration. While nominally 48 V DC, the PoE standard allows distribution of up to 57 V DC and requires equipment to be compatible with as low as 44 V input. The standard allows up to 2 A (~100 W), thus granting the benefits of NEC class 2 wiring. Each Ethernet run can power 3–4 typical 25 W luminaires; the number of luminaires is limited only by power and voltage drop. Naturally, PoE has been extended to lighting applications, providing a number of benefits in installation cost and system control. PoE is technically a DC distribution system, though is often powered by AC. In some ways, the typical PoE system moves the AC/DC conversion from distributed LED drivers to a centralized PoE switch. Some past research evaluates whether such PoE systems have any efficiency benefits over traditional AC lighting systems.⁵

We evaluate the following PoE value propositions in this study:

- **Simplified Installation:** Utilizes low voltage Ethernet cabling, automated provisioning, cutting down on installation time and complexity, materials, and labor costs
- **Reduced Infrastructure Costs:** Leverages existing network infrastructure, eliminating the need for separate power and data cabling and in many cases eliminates the need for conduit
- **Energy Efficiency Benefits:** Optimized POE lighting solutions provide better efficiency, saving buildings on operating costs

In addition, PoE asserts many other qualitative value propositions to ease the burden on installers, system designers, building managers, and occupants.

- **Increased Safety:** Provides low-voltage power, removing the risk of electrocutions, enabling simplified and cost-effective installation and operation

⁵ <https://cltc.ucdavis.edu/project/laboratory-evaluation-dc-lighting-systems>

- **Cyber Security:** Reduces 2.4 GHZ congestion from WIFI, Bluetooth Low Energy (BLE) mesh RF or Zigbee-based systems, and increased security posture with wired connections and existing IT architectures applied to OT

Finally, PoE claims to offer an improved interface with plug-and-play simplicity for the following benefits:

- **Enhanced Control, Flexibility, and Scalability:** Allows cloud- or on-premises-based centralized control and easy adjustment of lighting levels, schedules, and zones via software. Enables visibility across multiple properties, easily expandable and repeatable reconfiguration of lights without major infrastructure changes
- **Data and Integration with Other Systems:** Embedded sensors in fixtures and nodes stream data and can integrate with HVAC, security, and occupancy sensors for a cohesive building management approach and unlock new opportunities for optimizing operations
- **Remote Monitoring and Maintenance:** Enables proactive and automated maintenance through remote monitoring and diagnostics, reducing downtime and maintenance costs
- **Improved Lighting Quality:** Offers circadian rhythm lighting, enhancing comfort and productivity

While these characteristics can be available to AC lighting systems, PoE can greatly simplify the inclusion of these features. Thus, these qualitative value propositions can be considered as major advantages over traditional AC lighting systems, provided that the cost and energy benefits hold true.

The following table describes the exact PoE technology that was tested, measured, and evaluated in this study. Cisco provides the PoE switch equipment. They have partnered with Molex (Gateway-based) and MHT (Node-based), who each provide a different local lighting solution. Each vendor provides a software interface that translates automation commands for the PoE switch to transmit to the vendors' hardware. In a typical setup, (a) AC power flows through the PDU into the PoE switch, (b) the switch converts AC to DC, modulates data signal onto the DC, and transmits PoE from its ports to all connected Ethernet homeruns, (c) the PoE signal is received by a local PoE gateway (either standalone in the Gateway-based system or integrated into the node in the Node-based system), (d) the Gateway-based system can power 3-4 typical 25W LED luminaires within proximity of the gateway and the Node-based system can power 2⁶.

⁶ This number is based on the product set we tested. The Node-based company has additional products to allow daisy-chaining the 2-luminaire nodes, up to 90 watts. They have also since developed a SuperNode capable of powering up to 8 luminaires.

Table 3. Equipment Tested and Evaluated

Vendor	Item	Description	# Installed in WIL	# Tested @ LBNL
Cisco	PoE Switch	Network/routes power and data to devices, transmits PoE to Ethernet homeruns	1	1
Raritan	Power Distribution Unit (PDU)	Monitors and distributes power to multiple PoE switches	1	1
Molex	PoE Gateway	Receives ethernet homerun from switch, transmit 4-wire (non-Ethernet) power and data to local drivers	38	3
Molex	LED Driver	Receives 4-wire IEEE 1901 (non-Ethernet) power and data, powers and dims LED luminaire	81	3
Molex	Occupancy Sensor	Senses occupancy, reports up to switch	19	3
MHT	LED Driver/Gateway	Receives ethernet homerun from switch, powers and dims 2 local LED luminaires		2
MHT	Occupancy Sensor	Senses occupancy, reports up to switch		1
Intel	Nuc PC	Manages software that operates the PoE switch (used by either system)	1	2

After the WIL testing, Molex and MHT both announced a new software feature we refer to as port shutoff (PSO) functionality. GSA extended the project to evaluate the functionality and effect of PSO. The concept of PSO is to completely shut off various ports on the PoE switch at night to reduce standby losses. Several ports would still be enabled so their occupancy sensors, located at entrance ways, can detect whether somebody enters the lighting zone. If a person is detected, the PoE switch would enable all ports and turn on lights for a period of time.

In other demonstrations, Cisco has made efforts to integrate their occupancy data with HVAC systems, and demand-based control can now be done on terminal units as well as air handlers. Population heat maps are acquired via a combination of location data from devices connected to the wireless network, person counts from collaboration devices, and sensors connected to PoE solutions like the lighting systems. This information is then shared via an application programming interface (API) to the building management/automation system to fine tune their control loops based on actual heat load within the space. This in turn, allows the larger systems such as air handlers, chiller plants, and cooling towers to run at more optimal configurations due to the granular insight that is now visible through the connected

systems. Moving away from an optimal start/stop configuration and now controlling based on demand, we can see runtimes reduced in mechanical systems.

Cisco has demonstrated sensor integration with HVAC systems in their Paris location. Currently, such sensor integration has only been done internally on Cisco buildings and externally with a couple of customers. Cisco is working with major manufacturers such as Siemens, Schneider, and Honeywell to integrate the API and controls. In this fashion, Cisco's API allows the third party's controller to access population heat-map data, but Cisco does not actually control the HVAC.

M&V Plan

Testbed

The Workplace Innovation Lab (WIL) experiments with new office technologies that may be relevant to GSA buildings. It evaluates them on metrics such as energy consumption, thermal output, and user satisfaction. Successful technologies may be deployed in GSA buildings throughout the country.

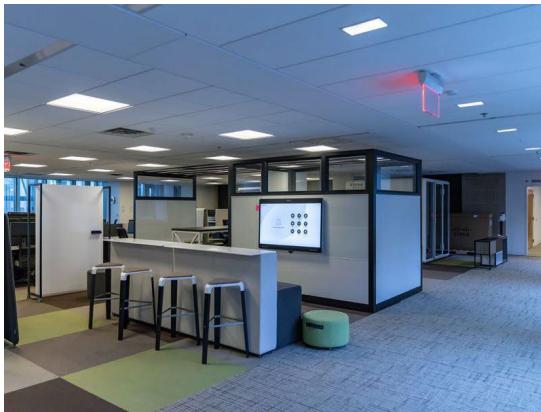


Figure 2. Picture from inside the Workplace Innovation Lab (WIL).

A PoE lighting system has been deployed in one wing of the WIL. These systems use a PoE switch to deliver combined power and data to PoE loads via Cat 5e (22 gauge) Ethernet cable. Each Ethernet home run passes through a Molex gateway, which converts the PoE form factor to a two-wire data and power signal. The gateways power up to three 20 W fixtures, often accompanied by an occupancy sensor that relays occupancy data to the PoE switch.

Table 4. Site Criteria

System	Portfolio-Wide Deployment	Testbed Pilot (Workplace Innovation Lab)
Facility Characteristics	Preference toward office space with plenum, ideally an already-planned lighting retrofit, has electrical/IT closet, known entrances to cubicle space where occupancy sensors can be placed	Office space with plenum, IT closet, and known entrances
Occupancy	At least 20 cubicles, no upper limit	Approximately 50 cubicles
Documentation	AC lighting circuit diagram and floorplan can be useful if doing a retrofit. Post-retrofit floorplan and PoE channel map documentation is mandatory for proper lighting system configuration	Post-retrofit lighting floor plan was available with PoE channel map
Lighting Controls	The PoE switch can run basic power control software, but any advanced lighting controls will be run on a PC connected to the PoE switch. Lighting control systems are provided by partner companies and allow building managers to create light maps and assign occupancy functionality	The Gateway-based lighting control system was used in the WIL pilot
Building Size	At least 1000 sqft is ideal, and no upper limit	5,662 square feet were used, which covered a third of one floor

Our team conducted additional testing at LBNL within a FLEXLAB® support space. The bench test setup includes a PoE switch, three Molex Gateways, nine luminaires, three sensors, and a computer necessary for IT and wireless support. This setup is used for an in-depth measurement of the PoE switch standby power and accuracy. We measured input power using a Chroma 66204 power meter. We used this bench test setup to evaluate the standby and port shut-off functionality of the Node-based system, which combines gateway and drivers into a single unit.

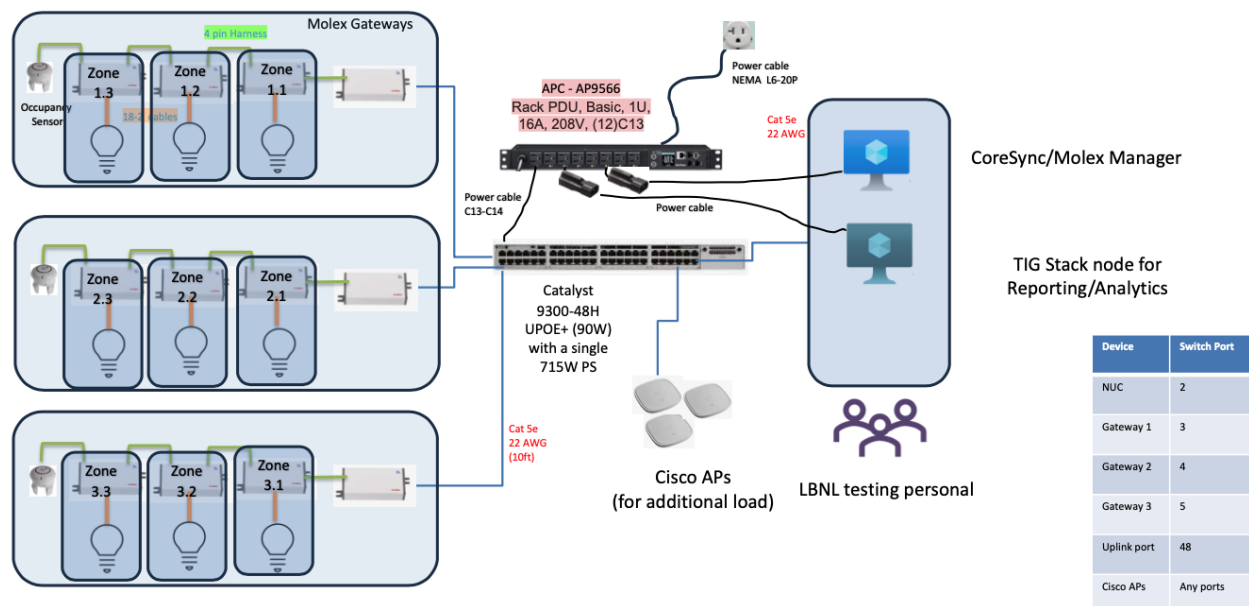


Figure 3. Diagram of the PoE testing setup in LBNL's FLEXLAB.



Figure 4. Picture from the PoE lighting rack test setup in LBNL's FLEXLAB.

M&V Design

We have tested, measured, and modeled various features of the PoE system related to the following use case metrics, all of which are described in the following sections:

Use Case	UC Name	UC Description and Goal	Metric
UC-1	DC-microgrid efficiency	Reduced energy consumption with PoE vs. equivalent AC system	Lighting System Efficiency (%)
UC-2	Energy reporting	Accuracy of vendor's energy reporting within 5% error	Percent Error (%)
UC-3	Sensor integration	Demonstrate capability to control HVAC based on real time occupancy, and provide heat maps for space utilization and/or daily occupancy	Qualitative Evaluation
UC-4	Lighting standby power	Hardware minimizes standby power losses	System Standby Power (W)
UC-5	Total cost	POE architecture has equal or lower upfront and operating cost relative to code compliant AC line voltage general office lighting for a new installation	Capital and Operating Costs (\$)

UC-1: DC-microgrid efficiency

The whole-system efficiency is affected by standby, conversion, and wire loss. To characterize the losses in the entire system, we would have to put a meter before and after every single wire and converter, which was not feasible. Instead, we use the Measurement-Informed Modelling Method,⁷ a tested method that takes information from what meters are available and models the rest of the building. We use metered data at the PoE switch output ports from two three-day periods: **12/6/23 to 12/9/23** and **12/12/23 to 12/15/23**.

We derive the following electrical models for the DC PoE and equivalent AC systems.

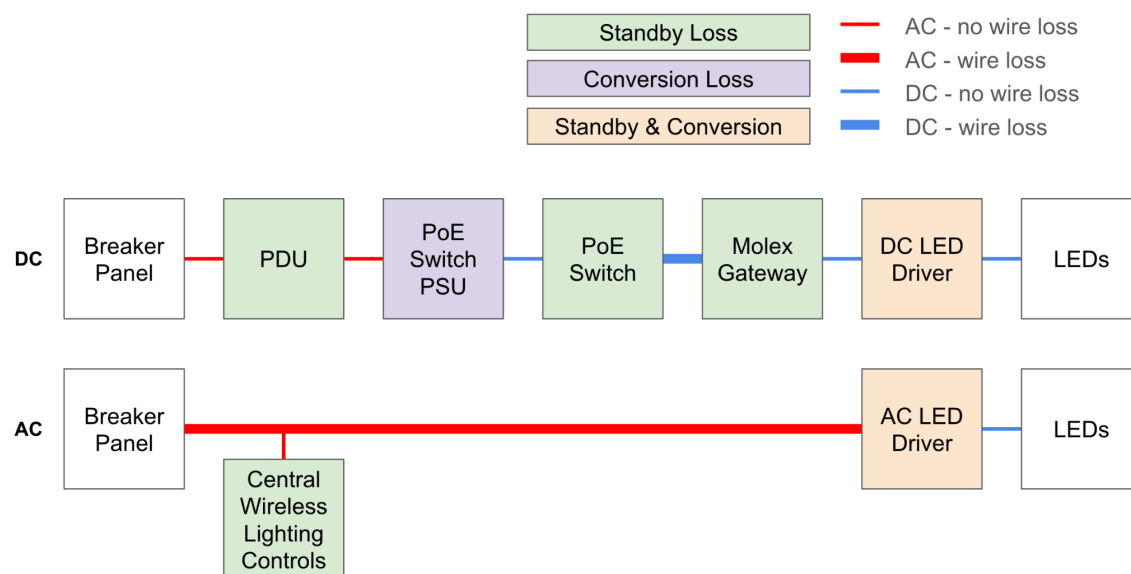


Figure 5. Single line diagram depicting sources of loss in the PoE and AC lighting systems.

⁷ <https://www.sciencedirect.com/science/article/abs/pii/S0306261921015658>

Based on measurements or datasheets, we can model the standby (more below in UC-4) and conversion loss in each block. We can calculate the load power (i.e., the power going into the LEDs). We then use that same load power in the AC building and back-solve to determine the AC building losses. In this way, we establish an “apples-to-apples” comparison between DC PoE LED lighting and AC LED lighting.

Once we have calculated the total loss and load energy in each system over the period of performance, we can solve for the system efficiency with the following formula:

$$\text{Efficiency} = 1 - (\text{Total Loss} / (\text{Total Loss} + \text{Total Load}))$$

Nightly port shut-off (PSO) functions will affect the system efficiency. To model this, we set the night hours at 10PM–6AM, during which all but four entrance-way ports shut off. During the several overnight instances that an occupancy sensor is activated, we turn on all ports, but only the lights of the affected zone.

In total, we derive and simulate the following system models:

- AC – Fluorescent System
- AC – LED System
- AC – High-Performance LED System
- DC – PoE System with Gateway-based system (installed in WIL)
- DC – PoE System with Gateway-based system and PSO
- DC – PoE System with Node-based system
- DC – PoE System with Node-based system and PSO
- DC – Optimized PoE System
- DC – Optimized PoE System with PSO
- DC – Optimized PoE System with PSO and DC Input

We model three AC systems: (a) a fluorescent system normalized for the same luminous output as LEDs, (b) an LED system with typical commercial AC LED drivers, (c) an LED system with high-efficiency but costlier AC LED drivers. The PoE system installed in the WIL was designed for flexibility, enabling its continued use in future building experiments. To fully evaluate PoE as a technology, we also simulate the Optimized PoE models to explore the technology’s potential if it were optimized for energy rather than flexibility. Such an optimized system is not currently installed in a GSA building, but could be designed and installed from off-the-shelf parts. See the Quantitative Performance Objectives table above for further description of these systems. The last model further extrapolates the potential of using PoE in a DC building, DC-coupled directly to solar and storage.

UC-2: Energy reporting

Although the PoE switch measures the power from each of its ports, integrated power measurement is not always accurate and may require verification over the operating power range. We evaluate accuracy in our bench-scale test. We test the accuracy of three of the PoE switch ports, each powering three luminaires. Our ground truth measurement is the average of several PoE testers, which we compare to the power readout from the PoE switch. For each port, we sweep the LED dimming and measure at several power levels to derive an accuracy curve and ultimately a calibration factor.

UC-3: Sensor integration

We qualitatively evaluate the capability of the PoE system to provide occupancy heat maps and control HVAC based on Cisco's presentation of the technology.

UC-4: Lighting standby power

The PoE switch requires some base power for processing and fans; this standby power can have a large impact on the overall system efficiency. In addition, the 38 Gateway-based system gateways, 19 occupancy sensors, and 81 LED drivers may each have relatively low standby but add up over the full system. We use a combination of bench testing and datasheets to determine the expected standby power of every block in the system. We then aggregate these values to determine the total standby power consumption.

The Optimized PoE System assumes a PoE switch with 0.5 W of standby per port, based on the IST 24-port switch (9W standby), conservatively extrapolated to 38 ports. It also assumes there is no PDU, and that the LED drivers can take PoE directly, obviating the need for a gateway. These assumptions are all based on existing market products.

In this task we qualitatively evaluate the functionality of the PSO functionality of the Gateway-based and Node-based system software.

UC-5: Return on investment

Cisco contracted Stantec to perform a capital cost analysis of deploying the same lighting systems across a set of broadly-representative cities: Seattle, Chicago, New York, and Dallas. Stantec built cost models with two AC lighting systems (Lutron and nLight) and two PoE lighting systems (Gateway-based and Node-based) in a 58,000 square foot office building. Stantec breaks the system cost into 26 cost categories, and further subdivides these costs as materials, labor, and commissioning. The Stantec report titled "WIRED FOR FUTURE: "Navigating PoE Lighting Economics" was delivered in July 2024. We studied these results in the context of validating the cost-based value propositions of PoE.

In this task, we further refine the capital costs of the Stantec report. First, we note that Cisco has nearly obtained UL924 for their PoE switches, allowing the switches to take a role. UL924 systems will greatly reduce the total capital cost since the system no longer needs an additional emergency lighting system. Thus, we model the UL924 PoE system separately to see the impact of this certification. In addition, we note that the Stantec analysis used electrician rates for the entire PoE installation. Our analysis accounts for the use of low-voltage electrical installers, who can complete the ethernet and controls cabling at a lower cost.

We also calculate operating costs for the building modelled in the Stantec report, modelling the energy and maintenance costs. Energy costs are based on a typical rate structure present in the four cities. Lighting energy usage is derived from the PoE reference buildings, modified for the appropriate lighting type and square footage. Lighting energy usage in the PoE building is further modelled to reflect the efficiency results in UC-1. Maintenance costs are derived from online and verbal sources and are modelled to reflect cost variance across the cities and lighting systems.

Installation, operations and maintenance impacts

To understand the installation, maintenance, and operations impacts of the PoE technology at the WIL, the project team conducted semi-structured conversations that included GSA IT personnel as well as personnel from the contractor that led the PoE design and commissioning.

Results

Quantitative Results

The quantitative results are presented as follows.

UC-1: DC-microgrid efficiency

The following table summarizes the results of the system efficiency study:

Table 5. System Efficiency

System Model	Efficiency (%) for 12/6/23 Dataset	Efficiency (%) for 12/12/23 Dataset
AC – Fluorescent System	33.5	32.7
AC – LED System (Equivalent AC Low)	50.6	48.8
AC – High-Performance LED System (Equivalent AC High)	52.8	50.8
DC – PoE System with Gateway-based system (Testbed PoE)	42.1	40.7
DC – PoE System with Gateway-based system and PSO	46.3	45.1
DC – PoE System with Node-based system	56.0	54.3
DC – PoE System with Node-based system and PSO (Typical PoE)	57.7	56.1
DC – Optimized PoE System	66.6	65.3
DC – Optimized PoE System with PSO (Optimal PoE)	69.1	68.0
DC – Optimized PoE System with PSO and DC Input	73.1	72.0

The existing PoE system installed in the WIL is 8.6% less efficient than a baseline AC LED lighting system and 10.5% less than a high-performance AC LED system. As previously mentioned, the existing system was designed for experimentation and flexibility and is not optimized to minimize energy consumption. The Gateway-based system is highly flexible, supporting any type of 4-wire PoE device and up to 4 typical 25 W

luminaires, but comes with an increased standby consumption from the gateway and each driver. In contrast, the Node-based lighting system combines the gateway and two LED drivers into a single module with relatively low standby. Since standby consumption is the bulk of the PoE system losses, the Node-based system is more efficient than the AC LED systems. Our models show that with optimization, the lighting system efficiency can be up to 69.1%.

Besides standby power, we found the DC PoE system to have another disadvantage: the LED drivers only operate at 92% efficiency. In previous studies, we have found 48V DC LED drivers with an operating efficiency up to 98% (96% weighted median). It is possible that the additional electronics for PoE communications may cause the additional loss, or perhaps the power electronics in these LED drivers are not optimized. In contrast, our market survey of high-performance 277V AC LED drivers peak at 93% (though the weighted median of more typical AC LED drivers is 85%). Note that we do not improve the LED driver efficiency in the optimized PoE model.

Port shut-off (PSO) provides an across-the-board benefit in standby consumption, raising the system efficiency by 1.7% to 4.4%, depending on the system and dataset. Gateway-based systems benefit more than Node-based systems from PSO due to its larger port circuit standby consumption.

It is also interesting to note that the system efficiency can be improved by nearly 4% if the PoE system resides in a DC building, fed from a DC source, thereby eliminating conversion loss in the PoE switch's power supply unit. This is just an approximation of the savings potential in the lighting system, and a whole-building simulation would be required to more accurately model the efficiency of an entirely DC building with solar and storage.

Another important note is that the system efficiency changes between datasets. This is likely because the WIL saw more usage earlier in December. In systems with such high standby consumption, higher load almost always means higher system efficiency.

The following table describes the modelled loss breakdown for the existing WIL DC PoE system with Gateway-based system's drivers. The Optimized PoE system naturally has better standby. Losses in the AC LED System are more often due to conversion loss.

Table 6. Loss Breakdown for the 12/6/23 Dataset (% of total losses)

Type of Loss	Equivalent AC System	Testbed PoE System	Optimal PoE System
Standby	44.9%	84.4%	64.6%
Conversion	54.9%	5.2%	33.0%
Wire	0.2%	1.2%	2.4%

UC-2: Energy reporting

As shown in the figure below, we found that the three PoE ports we tested had less than 5% error when measuring power above 20 W. This percent error is fairly standard for this type of equipment and is neither exceptional nor concerning. For applications in which a higher accuracy is needed, we can derive a calibration factor, multiplying the measured port power by: $1/(Ae^{Bx} + 1)$, where $A = 0.361$ and $B = -0.100$.

Percent Error vs. Power

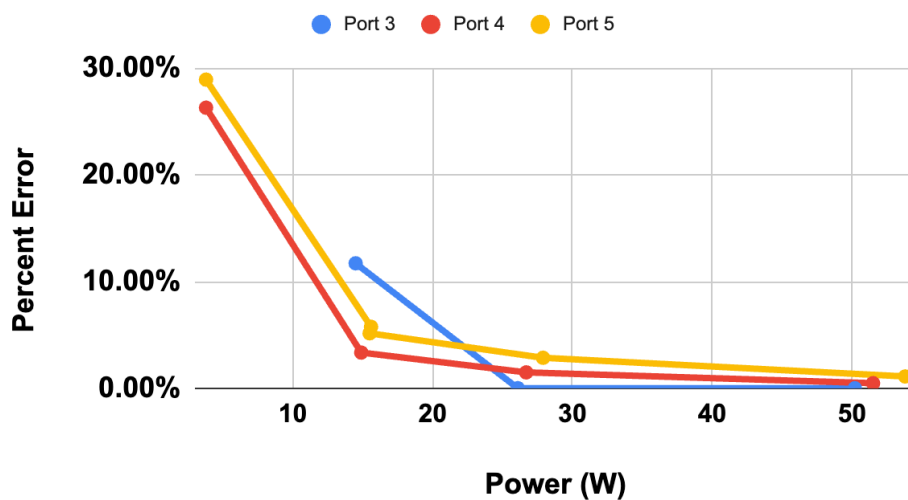


Figure 6. Accuracy results from the port measurement and calibration for ports used in LBNL's FLEXLAB.

UC-4: Lighting standby power

Standby power consumption is the electricity used by a device while it is powered but not actively operating. It is often the power needed to maintain connectivity, and is considered in energy analyses as unproductive loss. We measure the standby of the PoE switch and other lighting system components as a bench test. The chart below shows how enabling data, PoE, and power affects the standby measurements. With nothing enabled, the standby is 65.6 W. The standby increases by 0.053 W per port with PoE enabled, a nearly negligible difference. Enabling power to the port essentially adds the standby of the Gateway-based system's gateway, three LED drivers, and the sensor, which consistently total 4.5 W. When repeated with a node, we measured 1.6 W of standby. During the bench scale tests at LBNL, we also measured and confirmed the functionality of both the Gateway-based and Node-based system's PSO capabilities.

Input Power vs. Condition

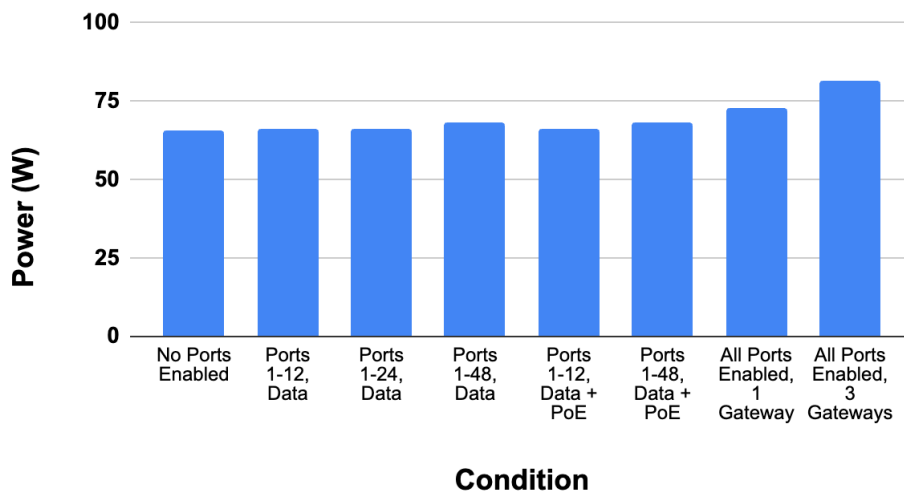


Figure 7. PoE switch standby consumption in various modes, measured in LBNL's FLEXLAB.

The standby accounting is shown in the following tables. Quantities for each component are determined based on the WIL floor plan. We assume the equivalent AC LED system is controlled over a wireless network. It requires wireless gateways, a PoE switch, and a computer that runs the controller software. The Optimized DC LED system assumes an energy-optimized PoE switch that averages 0.5 W standby per port and circuits with 0.7 W per LED driver.

Table 7. Standby of the DC PoE Lighting System with Gateway-based System's Drivers (Testbed PoE)

Component	Standby Each (W)	Quantity	Total Standby (W)
PoE Switch Baseline	65.6	1	65.6
PoE Switch Standby Per Port	0.053	38	2.0
PDU	2.35	1	2.4
Gateway-based System's Gateway	2.0	38	76.0
DC LED Driver	0.7	81	56.7
Sensor	0.4	19	7.6
Total			210.3

Table 8. Standby of the DC PoE Lighting System with Node-based Drivers (Typical PoE)

Component	Standby Each (W)	Quantity	Total Standby (W)
PoE Switch Baseline	65.6	1	65.6
PoE Switch Standby Per Port	0.053	38	2.0
PDU	2.35	1	2.4
Node-based system's Node	1.6	38	60.8
Sensor	0.25	19	4.8
Total			135.5

Table 9. Standby of an Equivalent AC Lighting System (Equivalent AC)

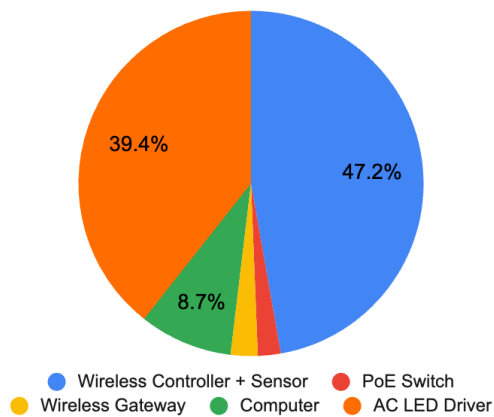
Component	Standby Each (W)	Quantity	Total Standby (W)
Wireless Controller + Sensor	0.6	81	48.6
PoE Switch	2.2	1	2.2
Wireless Gateway	1.3	2	2.6
Computer	9.0	1	9.0
AC LED Driver	0.5	81	40.5
Total			102.9

Table 10. Standby of an Optimized DC PoE Lighting System (Optimal PoE)

Component	Standby Each (W)	Quantity	Total Standby (W)
PoE Switch Standby Per Port	0.5	38	19.0
DC LED Driver	0.7	81	56.7
Sensor	0.4	19	7.6
Total			83.3

The following figures display a breakdown of the standby by component.

Equivalent AC Lighting System



Existing DC PoE Lighting System

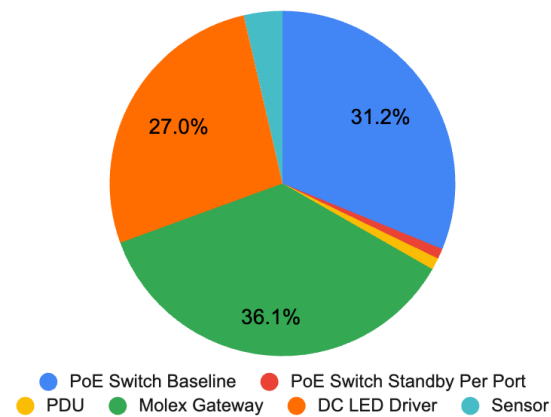


Figure 8. Breakdown of sources of standby consumption in AC (left) and Gateway-based DC (right) systems.

Cost-Effectiveness

UC-5: Capital and Operating Costs

We improved the data and calculations from the Stantec report to (a) disaggregate the capital cost categories, (b) improve accuracy of labor costs, and (c) extrapolate the capital costs of a UL924-certified PoE system. The following labor rates are used (b), based on the RSMeans⁸ cost index per city for electrician rates. Low-voltage installer rates are based on contract data from New York. Large markets such as New York and Chicago are more likely to have electrical installation firms that specialize in low voltage, whom we find offer lower rates at 50% the cost of an electrician. Smaller markets such as Dallas and Seattle have fewer installer options; thus, we assume the same electrical firm completes low-voltage and high-voltage work, only offering a 15.62% discount for low-voltage work. Note Dallas' significantly lower electrician rate, which was confirmed by multiple sources.

Table 11. Electrical Installation Rates by City and Laborer Type

City	Dallas	Chicago	New York	Seattle
Electrician Hourly Rate (RSMeans 2025)	\$46.20	\$102.50	\$131.60	\$99.50
Low-Voltage Installer Hourly Rate	\$38.98	\$51.25	\$65.80	\$83.95

⁸ RSMeans 2024 Cost Data

To compare overall technology cost, we define three generalized lighting systems calculated as the medians of cost variance by location: (a) AC lighting, (b) PoE lighting, and (c) UL924-certified PoE lighting. Based on these overall results, we conclude that PoE systems today cost 5.9% less than AC lighting systems. While AC systems have a lower material cost, PoE systems require less labor. We also study the breakdown between costs associated with wiring, fixtures, and other categories such as electronics and controls. Total wiring costs (materials and labor) for PoE are 10% lower than AC but are overall insignificant as wiring costs only account for 12–13% of total costs. We also note that Cat cabling is less expensive per foot, but buildings need more linear feet since each Ethernet homerun only powers 3 to 4 typical 25 W luminaires.

We also note PoE installations today require an entirely separate emergency lighting system, greatly increasing the total cost. Cisco is currently seeking UL924 certification, which would allow their devices to manage and provide emergency lighting. If we assume emergency lighting systems in UL924-listed PoE systems to cost the same as their AC counterparts, the PoE solution becomes 11.2% cheaper than the general AC lighting system. Note that GSA had a standard requirement that emergency PoE lighting utilize a red cable jacket while normal PoE cabling utilize a different jacket color than conventional IT cabling to allow for quick identification.

Cost Breakdown of AC vs PoE

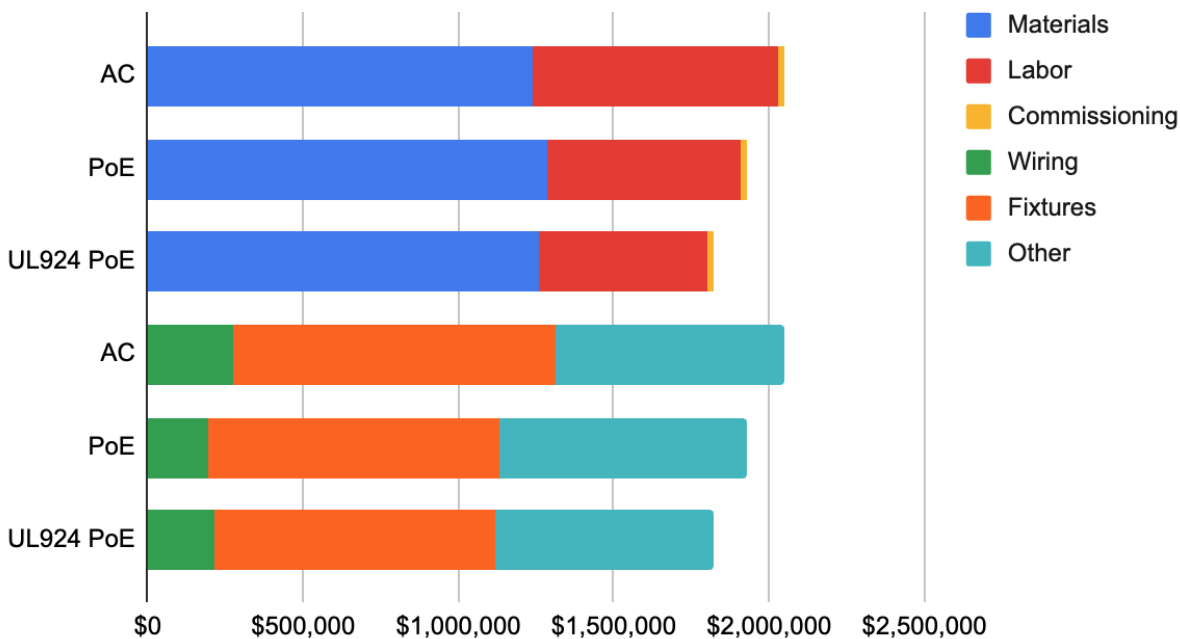


Figure 9. Cost breakdown of the 58,000 sqft Stantec building model (892 fixtures), averaged over the four cities, of an AC lighting system, PoE system, and PoE system after Cisco obtains UL924 certification. The top three rows show the cost breakdown of materials, labor, and commissioning, while the bottom three break the total cost down by material and labor costs associated with wiring, fixtures, and other costs.

There is a fairly significant cost discrepancy between the different lighting systems of the same type (AC or PoE), particularly between Lutron and nLight. This cost discrepancy is almost entirely related to the respective lighting control systems (the “other” category of the above charts).

Cost Breakdown of Solutions

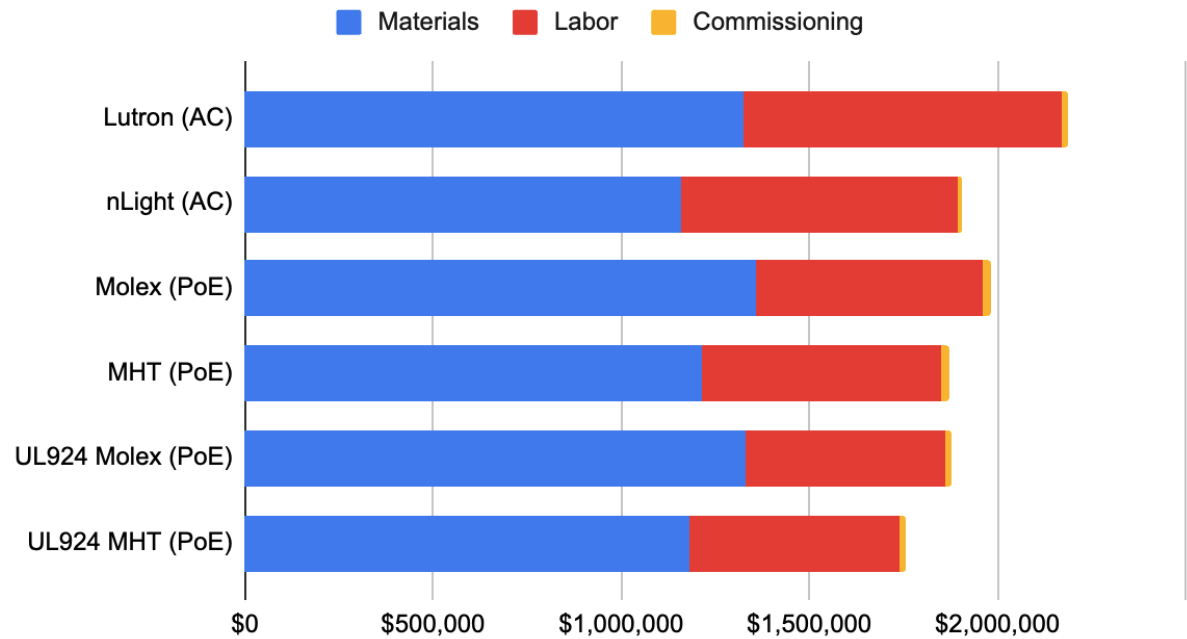


Figure 10. Modelled cost breakdown, averaged over the four cities, of each lighting system that was modelled.

We also note the cost variance by city, noting that PoE systems are considerably more expensive in Chicago. The Chicago PoE outlier highlights the potential for large cost variability; thus, we use the median instead of average to calculate our generalized system costs.

Cost Variance by City

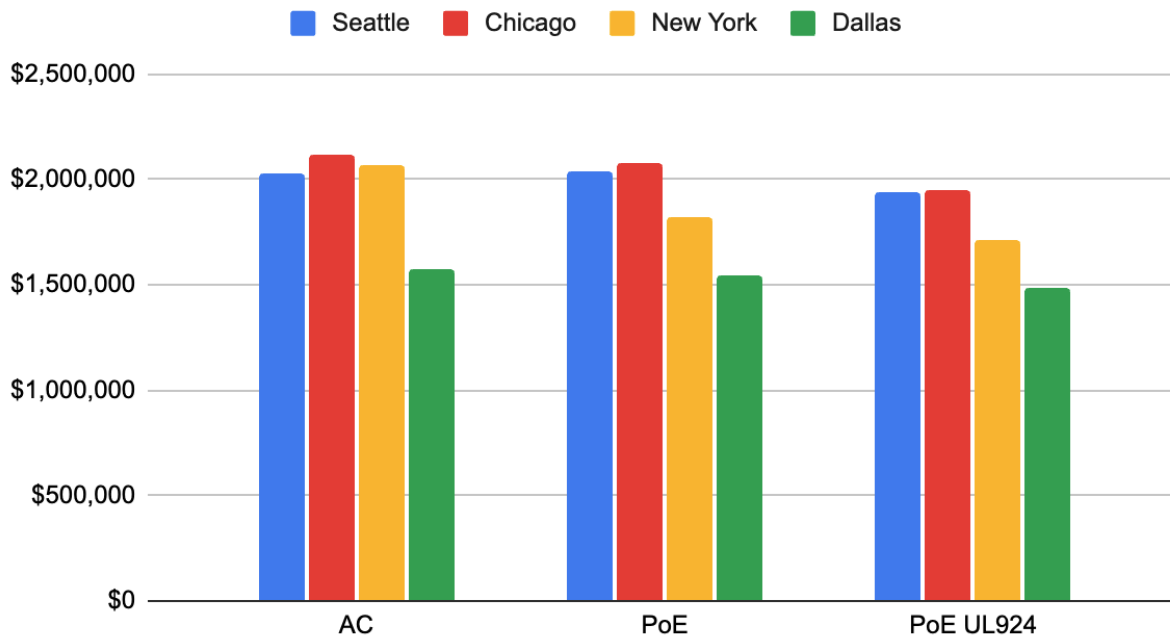


Figure 11. Modelled total cost of each system per city.

We also calculate the operating cost based on maintenance and energy costs, both reflected in the table below. Total building energy is modelled based on DOE reference building load profiles for a large office building, scaled to 58,000 square feet, with total input energy consumption derived from lighting system efficiency models. The modelled AC lighting system requires 111,186 kWh/yr (22.32 kWh/sqft/yr), and the DC PoE system requires 108,066 kWh/yr (21.69 kWh/sqft/yr).

Table 12. Electrical Installation Rates by City and Laborer Type

	Dallas	Chicago	New York	Seattle
AC Lighting System Annual Maintenance	\$5,501	\$12,153	\$16,137	\$12,199
DC Lighting System Annual Maintenance	\$4,731	\$7,790	\$8,682	\$11,272
Electricity Rate	\$0.085/kWh	\$0.136/kWh	\$0.23/kWh	\$0.119/kWh
AC System Annual Electricity Cost	\$9,451	\$15,121	\$25,573	\$13,231
AC System Annual Electricity Cost	\$1.90/sqft	\$3.04/sqft	\$5.13/sqft	\$2.66/sqft
DC System Annual Electricity Cost	\$9,186	\$14,697	\$24,855	\$12,860
DC System Annual Electricity Cost	\$1.84/sqft	\$2.95/sqft	\$4.99/sqft	\$2.58/sqft

Based on the capital and operating costs, we can derive the following overall table, which compares several cost metrics between AC and DC PoE lighting systems.

Table 13: Economic Assessment Worksheet

Feature	Industry-Standard Replacement (AC LED system)	Tested Technology (PoE DC LED system with UL924) ¹	Difference
Equipment and Materials Cost ²	\$1,242,210	\$1,256,358	-\$14,148
Installation and Labor Cost ³	\$805,484	\$562,006	\$243,478
Total Capital Cost per sqft	\$35/sqft	\$31/sqft	\$4/sqft
Annual Maintenance	\$12,176/yr	\$8,236/yr	\$3,940/yr
Annual Energy Consumption	111,186 kWh/yr	108,066 kWh/yr	3,120 kWh/yr
Annual Energy Consumption per sqft	22.32 kWh/sqft/yr	21.69 kWh/sqft/yr	0.63 kWh/sqft/yr
Annual Energy Costs per Square Foot (testbed utility @ \$0.11 kWh)	\$2.45/sqft/yr	\$2.39/sqft/yr	\$0.06/sqft/yr
Annual Energy Costs per Square Foot (Selected cities average @ \$0.14 kWh)	\$3.18/sqft/yr	\$3.09/sqft/yr	\$0.09/sqft/yr

Feature	Value
Simple Payback (GSA average)	0 years (both capital and operating costs are lower with PoE)
Savings-to-Investment Ratio (GSA average)	11%

¹ Use current technology costs provided by vendor and local utility rates and installation costs

² Equipment lifespan is 20 years

³ Labor is done by both electricians and low-voltage installers at their respective rates

Qualitative Results

The qualitative results are presented as follows.

Regarding the installation process, the major difference between this project and a more typical project was the removal of 800 lb. of electrical armored (BX) cables that previously powered AC luminaires and were made redundant by the PoE system, which was not a trivial effort. Also, the switch used was not a standard GSA switch and purchasing new switches was required when transitioning the project to the GSA network

from its initial separate configuration. The switches were new to GSA's IT personnel; this challenge was addressed through communication between GSA IT personnel and the vendor/contractors.

Once the transition of the system to GSA was complete, no serious operations and maintenance issues were raised by the building staff. In terms of cybersecurity this system doesn't represent a substantial difference with regards to normal GSA IT operations. As for physical infrastructure, the system uses existing network closets and doesn't require additional ventilation. The PoE system was installed as part of a package that also included a teleconferencing system designed to enhance hybrid collaboration; although its impacts were not the focus of this study, this hybrid teleconferencing system could potentially enhance the experience of the building occupants. One operational challenge introduced by the PoE system was that this meant that the lighting was not integrated with the other building systems monitored by the building automation system (BAS). However, at the time of the data gathering the process of integrating the lighting with the BAS was ongoing.

UC-3: Sensor integration

A qualitative overview of Cisco's HVAC integration efforts are summarized in the Technology Description section.

Conclusion

Summary Findings

Cisco deployed a PoE lighting system in a 5,662 sqft floor section of the GSA's Workplace Innovation Lab at the GSA headquarters office building. LBNL also tested a scaled down version of the same PoE lighting system in LBNL's FLEXLAB. Based on these experiments and extensive modelling and analysis, we found the following results:

- PoE lighting systems available today can be 6.2 percentage points more efficient than equivalent AC lighting systems, and we extrapolate further optimization can allow PoE lighting systems to be 17.7 percentage points more efficient than AC.
- Standby consumption dominates the losses in PoE systems, with standby accounting for up to 84% of losses in some PoE systems.
- PoE systems can self-measure the power from each port, and we find the accuracy of self-measurement to be sufficient for most use cases.
- PoE lighting systems, once UL924-certified, could have 11% lower capital costs than AC lighting systems.
- PoE lighting systems are expected to have generally lower maintenance costs due to ease of low-voltage maintenance, and lower electricity costs due to higher system energy efficiency.

Based on this study, we recommend:

- GSA further investigates which HVAC systems support PoE control and integration into the population heatmap. There may be a site that both (a) needs a lighting retrofit, and (b) has a compatible HVAC system.
- GSA installs PoE lighting systems such that there are clear entrances and exits to a zone, allowing for whole-zone occupancy detection and port shutoff capabilities.
- Product manufacturers and vendors pay attention to standby consumption in product design.

Lessons Learned and Best Practices

Energy Efficiency and Standby

The main lesson learned is that standby consumption dominates a lighting system's electrical losses. This study generated attention to the standby consumption of attached electronics, and in part motivated the partners to develop port shutoff capabilities in their systems.

The selection of PoE switch and lighting system (Node-based vs Gateway-based) will depend on whether project teams prefer flexibility or energy savings.

- The PoE switch must support the data rate and bandwidth of its connected loads. The Cisco information technology (IT) switch can support high bandwidth loads such as laptops and security cameras but has a high standby consumption. Systems designed exclusively to support low bandwidth loads (lighting, sensors, HVAC) can leverage standby-optimal PoE switches such as the IST 24-port 9W operational technology (OT) switch.
- The choice of end-use lighting system (i.e. last ~20 feet) is also influenced by system design preferences. The Gateway-based system is the flexible candidate and can support up to 4 typical 25 W luminaires, and/or any other device in the Gateway-based ecosystem. The Node-based system we tested is the energy-optimal candidate, powering 2 luminaires very efficiently.

Measurement Accuracy

The Cisco PoE switch's self-reporting of electrical power delivered by each port can be considered as accurate enough for most applications.

Installation and Procurement

Much of the installation work can be accomplished by low-voltage electrical workers, saving on installation cost. Some markets have separate low-voltage installation firms whose rates may be significantly lower than combined high/low-voltage electrician firms. Installations and retrofits must ensure adequate space in a network closet with power sufficient for the lighting system.

Key Takeaways

Based on the results of energy efficiency and capital costs, PoE is highly recommended for consideration in new construction, particularly for office buildings. There are not any particularly optimal site characteristics. If the site already plans to include a 48V power feed to the IT cabinet (e.g., BIPV), PoE systems will yield further benefits.

Sites already planning a major renovation/retrofit of their lighting systems can also benefit from PoE for all the reasons described above. Retrofit sites may also be suitable for localized generation options such as OREngE. Generally, PoE system cost scales reasonably well, enabling partial building retrofits floor by floor. Expanding the retrofit to a new floor requires a network closet with sufficient power for a PoE rack, but beyond that retrofits scale with square footage.

This report does not study the economics of minor retrofits, but we sense minor retrofits might not be quite as strong a candidate for PoE lighting. For example, a switch from fluorescent to LED T-8 tubes might not achieve the return on investment detailed in this report, since PoE would fundamentally require the effort to rewire entire lighting circuits. Sometimes the existing luminaire has an LED string that is compatible with the output voltage range of the PoE driver, in which case the driver can be swapped while keeping the luminaire. Swapping drivers could lower costs. If the existing drivers are inaccessible or challenging to remove, labor costs may rise and negate the benefits of re-using the luminaires.

Appendices

Data Sources

Table 14. Monitoring Points and Instrumentation

Monitoring Point	Logging Equipment Description	Location	Collection Period
PoE switch output ports	PoE switch self-measurement of output ports	Workplace Innovation Lab (WIL)	12/6/23 to 12/15/23

Glossary

Term	Definition
Gateway	A device that can receive and process PoE from the PoE switch via an Ethernet homerun
Gateway-based	PoE lighting systems based on the use of PoE gateways, which connect to a PoE homerun and convert the PoE power/data format to a simpler format for distribution to end-uses
Homerun	A long and direct connection from a gateway (PoE) or receptacle (AC) to the PoE switch or breaker, respectively
IST	A PoE lighting system and company, partnered with Cisco
LED Driver	Power electronics required to condition input AC or DC power to DC power appropriate to operate the LED luminaires at a desired dimming level
Molex	A PoE lighting system and company, partnered with Cisco, offering a Gateway-based solution
MHT	A PoE lighting system and company, partnered with Cisco, offering a Node-based solution
Node-based	PoE lighting systems based on the use of nodes, which consolidate the gateway, PoE splitter, communications, and LED driver into a single device
Power over Ethernet (PoE)	Power over Ethernet. An industry standard that allows data to be modulated onto power lines and transmitted over a wire. PoE mainly describes the communications protocol and voltage levels, but the wires could be 8-wire Ethernet cables, or other solutions (e.g. 4-wire Gateway-based PoE)
PoE Switch	A device that converts AC to 48 V DC power, modulates data onto the power lines at each port, and transmits PoE from its many ports over the Ethernet homeruns
Port Shutoff (PSO)	A control feature by Gateway-based and Node-based that allows the PoE switch to shut off all ports except those serving vital occupancy sensors, eliminating standby losses on these ports
Standby Power	Electrical power used by a device while it is powered but not actively operating in its designated function; standby power is often to maintain connectivity