The Demonstration of Power over Ethernet (PoE) Technologies in Commercial and Institutional Buildings

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ABSTRACT

PoE technologies are currently ubiquitous in offices in the form of phones, access points, and IP security cameras and managed by on-site IT staff. As low voltage DC-power capabilities have increased with network switches, PoE devices are now being integrated across additional building systems, including lighting, computers, and HVAC controls. Since PoE devices are connected to network switches, energy monitoring and management can be performed through the IT network management software. Data and results from technology validations are still very limited for PoE equipment. This lack of information hinders higher adoption as its benefits and challenges have been insufficiently quantified in real-world scenarios. The use of IT network switches to power and control lighting, plug loads, and HVAC were demonstrated at a variety of sites including offices, schools, and a hotel. This paper presents the findings of a three-year DOE-/State of Minnesota-funded project that demonstrated and assessed the energy and non-energy benefits of Power over Ethernet (PoE) technologies at four commercial/institutional sites. The goals of the demonstrations were to: (1) assess the receptiveness of commercial and institutional markets to these new technologies, (2) demonstrate the feasibility of PoE technologies within standard design/construction practices and commercial codes, (3) assess the energy and cost savings opportunities of these technologies, (4) provide energy management opportunities where they typically are not available, and (5) formulate approaches to spur adoption of these technologies in the marketplace.

Introduction

Power over Ethernet (PoE) was launched in 2000. In 2003, the Institute of Electrical and Electronics Engineers (IEEE) ratified the first PoE standard, IEEE 802.3af-2003, which set the maximum power load at 15.4 W DC drawn from each port of a network switch and transmitted over twisted-pair Ethernet cable. With the advent of PoE, it has become standard practice for local area networks (LANs) to power devices such as voice over Internet Protocol (VoIP) phones, Wi-Fi access points (APs), and IP security cameras using the same category cable that also transmits information/data between these devices and the building's data center.

Over the past 20 years, many PoE standards have been ratified, allowing increased levels of maximum power to be drawn from the network switch (also described as the power sourcing equipment, PSE) to each PoE powered device (PD). Table 1 shows the current PoE standards that are in effect.

Table 1. The evolution of the IEEE 802.3 PoE standard has broadened the application of PoE (Yseboodt and Abramson, 2018).

	Standard	Maximum power allowed in PSE	Power available to end device	Applications of PoE
2003	PoE 802.3af (802.3at Type 1)	15.4 W	12.95 W	Phones; Wireless access points
2009	PoE+ (802.3at Type 2)	30 W	25.50 W	+ LCD displays; HVAC controllers/sensors
2017	UPoE (802.3bt Type 3)	60 W	51 W	+ LED lighting; Thin client computers; smart building devices
2019	Higher-power PoE (802.3bt Type 4)	100 W	71 W	+ Laptops and TVs; LED bay lighting; Mini Fridges

The increased levels of low voltage DC power have allowed a greater variety of devices to be powered by PoE. The range of PDs includes LED lighting, computers (zero/thin clients, all-in-one quad-core computers with dual monitors), LCDs, HVAC controllers, ceiling fans, and window shades/actuators.

PoE technologies can provide several benefits over traditional alternating current (AC) technologies:

1. IT staff can control devices connected to network switches using vendor-supplied energy management software. The network management software allows IT staff to monitor the power draw at each port (i.e., submetering of each PD) and manage the power that can be drawn (i.e., energy management). This provides an energy management capability for sites where building automation systems (BASs) may not be in place (or where there is a BAS but not local control), with the associated energy savings opportunities from advanced sensors and controls.
2. Since electronic devices like LED lighting and computers run on DC power, when they are powered by AC electricity, the power must be converted to DC using converters. Rectifying the power from AC to DC at a central location, the network switch, is inherently more efficient than multiple conversions at the individual electronic devices. As an example, AC adapters or "wall warts" can have losses of 15 – 50% (Coeztee, 2016).
3. The low-voltage DC power of PoE (below 50V) can be advantageous due to safety. The ethernet cables and PDs are touch-safe.
4. A non-energy benefit is that installation costs may be lowered since the cost of low voltage wiring is typically less expensive than AC electrical wiring. Additionally, PoE networked devices will not require the additional electrical service required for the analogous AC-powered networked devices.

5. Reconfigurability can become a driving factor as single touch-safe cable and devices can be installed in spaces where no AC outlets may be accessible. Non-electricians, such as IT personnel or staff, can re-configure PoE lighting fixtures or other devices as needed to adapt to the changing needs of the space.

Since the PDs are networked, these PoE devices can be integrated across other networked building systems to increase the building's overall energy efficiency and operation.

This paper will describe the current efforts of a three-year project funded by the U.S. Department of Energy and the State of Minnesota.[1] The project has recruited commercial and institutional sites to demonstrate and assess these PoE technologies in two or more building systems which include: (1) lighting/electrical, (2) plug, (3) energy management and information, and (4) sensors and controls. The goals of the project are to understand:

1. The energy and non-energy benefits of these technologies and systems,
2. The technical and economic barriers and opportunities may exist to adoption of these existing technologies for energy saving purposes, and
3. The feasibility of implementing these PoE technologies within standard design/construction practices and under existing commercial codes.

The project team includes the Center for Energy and Environment (CEE); the architectural firms LHB and Wold Architects who assisted in recruitment and provided design and engineering services; and Xcel Energy who provided guidance and advice on technical and program issues. The National Renewable Energy Laboratory (NREL) provided third-party measurement and verification (M&V). The project began in the Fall of 2017 and is expected to be completed in the Fall of 2020. Over the three-year length of the project covers, many PoE technologies and systems will be demonstrated at five sites.

The goals of the demonstration sites were to: (1) assess the receptiveness of commercial and institutional markets to these new technologies, (2) demonstrate the feasibility of PoE technologies within standard design/construction practices and commercial codes, (3) assess the energy and cost savings opportunities of these technologies, (4) provide energy management opportunities where they typically are not available, and (5) formulate approaches to spur adoption of these technologies in the marketplace.

Demonstration Sites

Over the first 18 months of the project or Budget Period 1 (BP1), two sites were recruited: (1) CEE's Minneapolis, MN Administrative Office and Lending Center and (2) Edina,

[1] This project is supported in part by grants from the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy under the Award Number EE0008191 (https://www.energy.gov/eere/buildings/articles/funding-opportunity-scaling-next-generation-building-efficiency-packages) and from the Minnesota Department of Commerce, Division of Energy Resources through the Conservation Applied Research and Development (CARD) program (https://mn.gov/commerce/industries/energy/utilities/cip/applied-research-development/).

MN Public School District's South View Middle School and District Media and Technology Services (DMTS) Offices. For the second half of the project (BP2), three additional demonstration sites will be studied. Given the current timing of the project, this paper will only discuss the two demonstration sites of BP1.

NREL was designated by DOE to perform the 3rd party M&V for this project. NREL developed instrumentation packages for monitoring electrical use at the BP1 demonstration sites. Circuits directly connected to breaker panels (e.g., lights and data center equipment) were monitored using billing grade submetering equipment (eGauge meters and CTs). Circuits connected to AC power outlets were monitored using HOBO data loggers. PoE equipment was monitored using the built-in monitoring capabilities of the network management software. The data were collected onsite and uploaded via the host site network to NREL for storage and analysis.

CEE's Minneapolis, MN Administrative Office and Lending Center

Lighting. In Q1 of 2018, a renovation of the open central area of CEE's Administrative Office was performed which consisted of the installation of 17 new cubicles (in adjacent rows consisting of nine and eight cubicles, respectively). The office was instrumented with new PoE equipment through a remodeling effort. The renovation consisted of the installation of 17 new cubicles (in adjacent rows consisting of nine and eight cubicles, respectively). For the one row of nine cubicles, a Signify Ledalite 4' suspended PoE luminaire[2] was installed over each cubicle. The adjacent row of eight cubicles was illuminated by the legacy 2x4 T8 fluorescent suspended lighting system which consists of a row of 13 fixtures.

In Q4 of 2018, the T8 fluorescent tubes into the existing AC-powered fixtures were replaced with AC-powered LED lamps to allow the PoE LEDs to be compared with AC LED replacements. Figure 1 shows the layout of the cubicles with the two respective lighting systems along with a photo of the space.

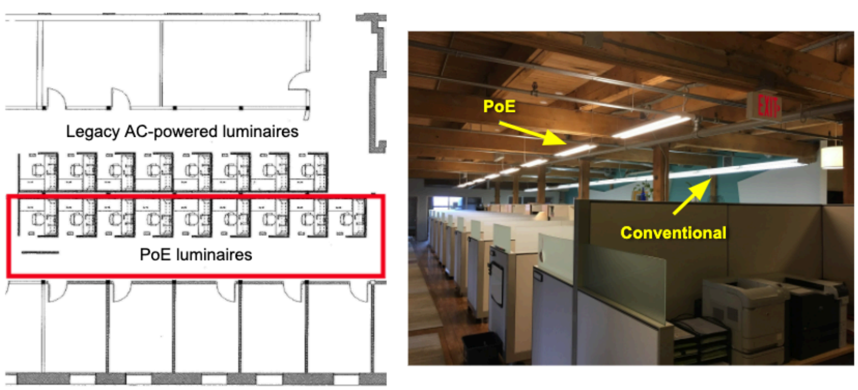

Figure 1. Floor Map and Photo of the PoE and Legacy Lighting Systems in the CEE Administrative Office.

[2] https://www.signify.com/en-us/products/indoor-luminaires/linear/suspended/floatplane-suspended

A control-treatment evaluation was performed to compare the energy use of the PoE lights against a base case of standard AC T8 fluorescent lamps in the original fixtures in the space and then against the energy use of the original fixtures equipped with AC LED replacement lamps. Since one 4' suspended PoE luminaire hangs over each cubicle of the treatment group, the comparison of the AC-powered lighting versus the PoE LED lighting system was performed per fixture. **Error! Reference source not found.** shows the comparison of the average AC-powered fixture containing either T8 fluorescent lamps or LED replacement lamps versus the PoE LED fixture. The LED lamps for both the AC and PoE fixtures were manufactured by Philips with a color temperature of 4000K.

Table 2. AC-Powered Light Fixtures with PoE Light Fixtures.

	AC-Powered Suspended Fixture with Ballast		Signify PoE Suspended Fixture	
	T8 Lamps	LED Lamps	100%	Dimmed
Load per Fixture (Watts)	58	26	31	16
Standby (Watts)	0	0	2	2
Average Cubicle Illuminance (footcandles)	40	41	23	-

The line-voltage fixtures could not be dimmed and the brightness was 100% while the brightness of each PoE fixture was set to the preference of each office worker (ranging from 15% to 75%). The cubicles lit by the legacy fixtures had a higher illuminance since each cubicle was illuminated by about 2 fixtures while the PoE cubicles were illuminated by one overhead fixture. The AC-powered fixtures are controlled by a wall switch. Each PoE light is controlled by the motion sensor in the fixture which is always active, as is its photocell. This explains the standby/baseload power of the PoE luminaire. The PoE fixture power draw is measured at the network switch port that the fixture is connected to. An additional standby/baseload power load of the PoE lighting system is the power drawn by the network switch as it communicates with the LAN. This is the energy cost for having networked lighting control (NLC), which would also occur with an AC-powered NLC system.

Computer Workstation. In one of the PoE cubicles, an AC-powered desktop PC workstation with two external monitors was replaced by a ThinLabs Dual Screen PoE All-in-One quad-core computer.[3] The workstation was used primarily for word processing, spreadsheets, business correspondence, and online webinars/training. A pre-post evaluation was performed. The staff person reported no difference in performance between the two workstations for the tasks performed. Power and energy data were collected at the cubicle with the original AC-powered PC workstation with dual AC-powered external monitors. The workstation was then replaced by

[3] https://www.thinlabs.com/products/dual-monitor-poe-computers

the ThinLabs workstation which was first powered using an AC-adapter and then powered by PoE. Table 3 shows the comparison of power loads for the two machines.

Table 3. Power Loads of an AC-Powered and a PoE Workstation in CEE Admin Cubicle.

Cubicle Workstation		Computer Power Load (Watts)		
		High Activity	Normal Activity	Standby
PC with two external monitors		40 - 95	16 - 40	0 - 2
ThinLabs AiO computer with dual monitors	AC-Powered	29 - 44	7 - 29	3 - 5
	PoE	29 - 47	8 - 25	4 - 5

The power requirements of the ThinLabs workstation are very similar whether powered by its AC-adapter or by PoE. The standby power for the PoE-powered ThinLabs workstation is the measured power to the port of the network switch.

Thin Clients. In the adjacent Lending Center space, eight 10ZiG PoE-thin clients[4] replaced the thin clients currently used by Lending Center staff. Each PoE-thin client was connected to the existing two AC-powered external monitors that had previously be in place. A pre-post evaluation was performed. Power and energy data were collected from the original AC-powered thin clients and monitors at each of the Lending Center cubicles before replacing the AC thin clients with the 10ZiG thin clients. The 10ZiG thin clients were powered in two modes: (1) using AC line power connected with the AC adapter supplied by 10ZiG and (2) using PoE connected by Ethernet cable to a PoE+ switch. **Error! Reference source not found.** compares the power loads for the three cases. The measured PoE thin client standby load is the power to the port of the PoE+ switch to which the thin clients are connected.

Table 4. Power Loads of AC and PoE Thin Clients in the CEE Lending Center.

Power (Watts)	Hewlett-Packard Thin Client	10ZiG Thin Client	
		AC-Powered	PoE+
Average	9 - 18	5 - 12	5 - 8
Standby	0 - 1.0	0.5 - 0.7	1.0 - 1.3

The power load of the external monitors ranged from 22 W to 42 W depending on the age and make of the monitor. The standby load of the monitors was about 1 W. The total load of the two monitors is on average about 60 W and with the PoE thin client, the load is about 66 W. Solely based on power demand, using the ThinLabs AiO with dual monitors would be preferable to the PoE thin client connected to two AC-powered external monitors.

[4] https://www.10zig.com/thin_clients

Network Switches. The network switches that powered and controlled these devices were located in the network closet situated between the Administrative Office Space and the Lending Center. Two Cisco Catalyst CDB-8U network switches[5] powered the eight PoE lights, wall light switch, and ThinLabs computer while a PoE+ network switch powered the 10ZiG thin clients.

Edina, MN Public School District's South View Middle School and District Media and Technology Services (DMTS) Offices

Classroom Lighting. Two classrooms at the South View Middle School in Edina, MN had new lighting equipment installed through a remodeling effort. The renovation was a school-wide effort that involves multiple classrooms and floors. The PoE demonstration took place in two adjacent classrooms: classrooms A211 and A212 that had new lighting equipment installed. Both classrooms have daylight coming through an existing south window. The original lighting in each classroom was 12 - 2x4 troffers, each containing three 4' T8 fluorescent lamps. The classrooms are used during the year for elementary school classes (5th and 6th grade).

Classroom A211 had HE Williams/Igor PoE luminaires installed while A212 served as the AC line voltage baseline for the LED equipment. In room A211, 16 PoE 2x2 troffers were installed while the control room A212 accommodated 12 AC-powered 2x4 troffers. The two systems provide equivalent light output to the two classrooms. The PoE lighting system was controlled through two Cisco Catalyst CDB-8U network switches, wall switches inside the classroom that allowed dimming and color temperature tuning, occupancy sensors, and daylighting control. The line voltage LED system was controlled by wall switches, occupancy sensors, and photocells and the LED lamps were dimmable but not color tunable. Figure 2 shows the layout of the two classrooms.

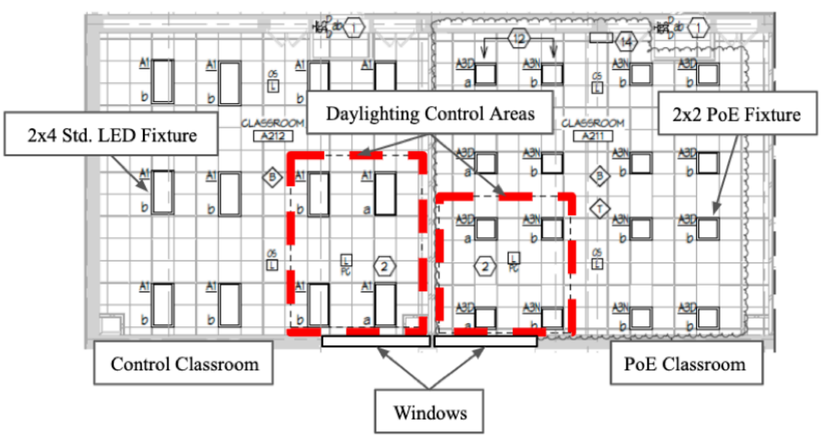

Figure 2. Floor Map and Photo of the PoE and Control Lighting Systems in the SVMS Classrooms.

[5] https://www.cisco.com/c/en/us/support/switches/catalyst-cdb-8u-switch/model.html

The power consumption as a function of average lighting levels (from 42 equally-spaced readings) measured at desk height was estimated for both classrooms. Error! Reference source not found. shows the performance of the line voltage 2x4 troffers and the PoE 2x2 troffers.

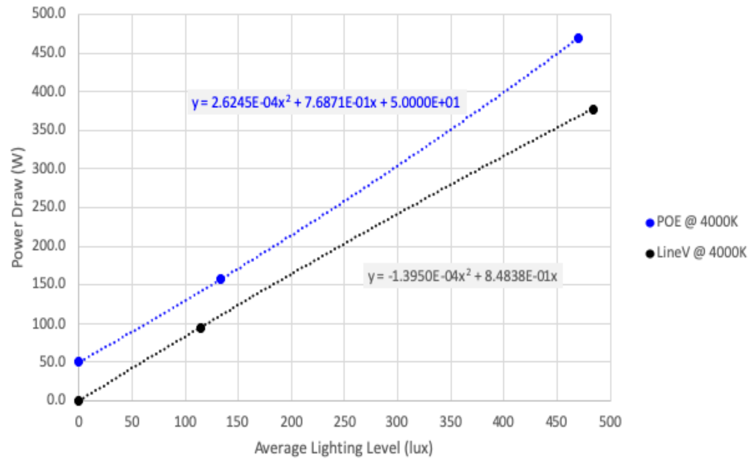

Figure 3. Light and Power Measurements of the Edina SVMS Line Voltage and PoE Classrooms.

The lighting performance of the two systems are comparable (similar slopes) but the PoE system has a non-zero y-intercept of about 50 W. This is the standby/baseload power that is associated with the network switch needed for PoE and the network control that comes with the lighting system. The AC-powered lighting system of the control classroom does not have network control. Comparing the PoE system to an AC-powered Digital Addressable Lighting Interface (DALI) lighting system or a Digital Multiplex (DMX) lighting system would have been a more apples-to-apples comparison in both functionality and standby/baseload needs.

At an average lighting level of 470 lux for each of the classrooms, the power for the line voltage fixtures was 368 W while the PoE lighting system was 469 W. The power to the original lighting system of 2x4 troffers with T8 lamps was about 1289 W so both LED systems provided a signification power reduction over the original T8 lights.

Upon examination of power use profiles at different points in the year for each classroom's lighting system (**Error! Reference source not found.**), PoE power consumption is consistently higher than the traditional AC lighting system.

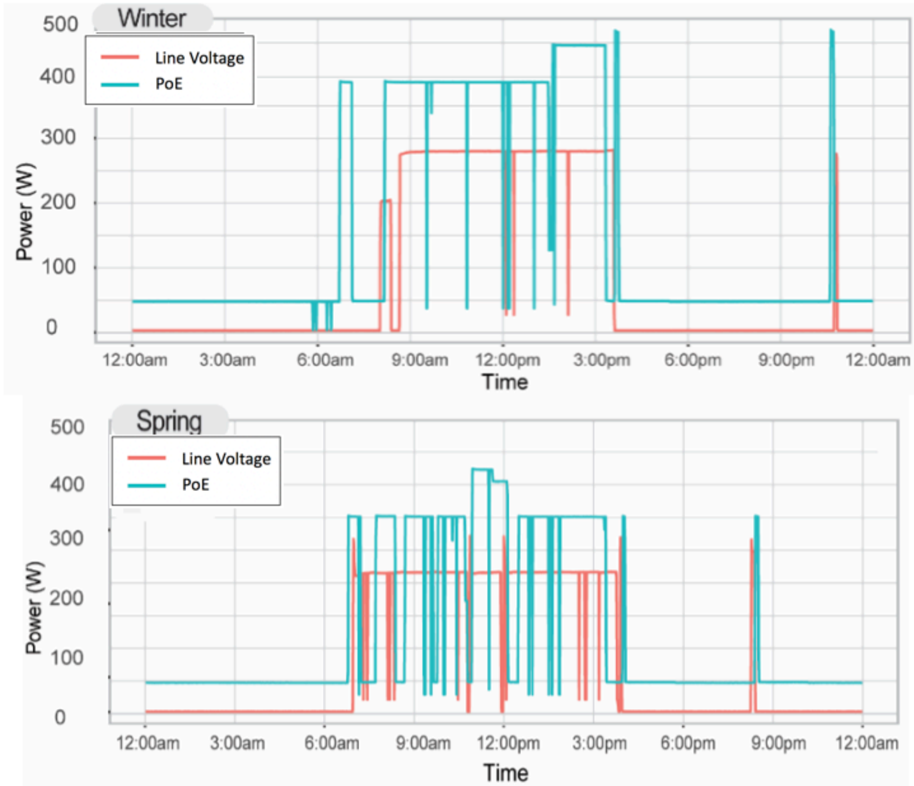

Figure 4. Power use profiles for each system over a typical day in winter and spring. The winter profile is for January 15th, 2019. The spring profile is for April 16th, 2019.

To further investigate the component-level power use of the PoE system, we broke down the power draw by non-effective and effective sources in the PoE system. We define ***non-effective power*** as power draw by the network switch or a powered device that produces no work perceived by the user. In the example of lighting, the power draw for control processes or AC-DC conversion losses within the node or network switch that is not directly translated into the output of light is non-effective power. ***Effective power*** is power draw from device hardware that is directly translated into work as perceived by the user. For lighting applications, this is the power draw from the LED fixtures that produces light. At 0% lighting, all power is non-effective power from the nodes and additional sources in the system, including potential cable losses.

For PoE systems, ***non-effective power*** can be a sizable portion of total power as seen for the PoE classroom data in **Error! Reference source not found.**. CLTC (2019) reported efficiencies of 73-75% from their laboratory evaluation with two PoE systems using maximum of 100m cabling.

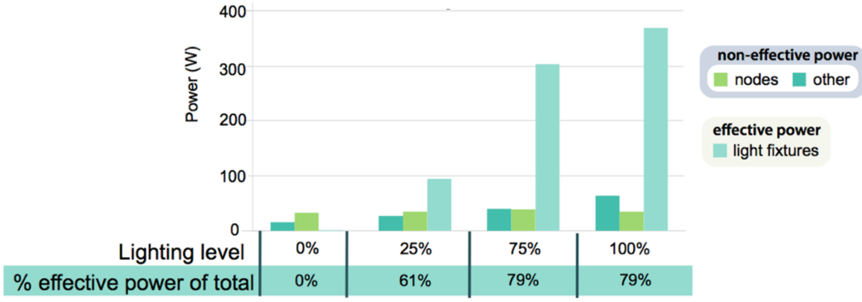

Figure 5. Breakdown of non-effective and effective power at different lighting levels in a PoE system. Other power includes non-effective power in the power source equipment, cable losses, and additional sources of non-effective power not yet identified.

Error! Reference source not found. presents a power comparison between both systems during illuminated and dark periods. Illuminated and dark labels correspond to periods when lights are on and off, respectively. During dark periods or periods at which each system is drawing power at a level comparable to that measured at a 0% lighting level, PoE indisputably draws more power for standby processes than the traditional line voltage system. Standby power draw in the PoE system is 49 W. This is significantly greater than standby power in the traditional AC system, 3 W. The difference is attributed to the power required by the network switch (approx. 15 W) and the PD nodes (approx. 34 W for 16 devices) to stay online, send data, and expect commands. This can be considered the energy cost for networked luminaire-level lighting control with occupancy and photosensors.

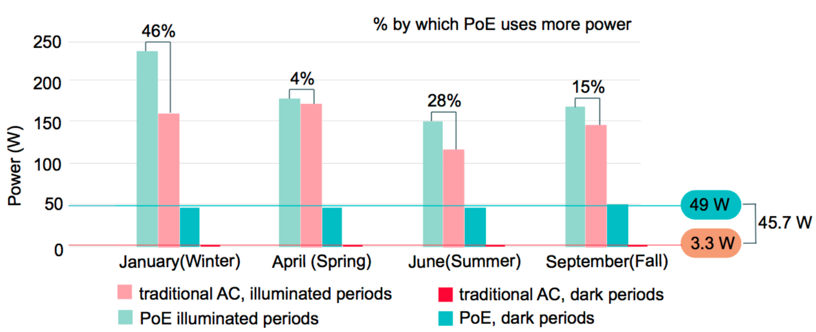

Figure 6. Comparison of average monthly power consumption for each classroom during illuminated and dark periods. The percentage by which the PoE system average power draw is greater than that of the traditional AC system is shown for illuminated times. However, illuminated data does not account for differences in lumen output and other uncontrollable variables (e.g. teacher lighting preferences).

Media Center Research Workstations. In the SVMS Media Center, a comparison was performed between the 10ZiG PoE thin client with a Chromebook and an Intel Compute Stick. The three devices were set up in SVMS' Media Center as reference stations for general student use. Each of these devices was connected to AC-powered LED displays. Table 5 compares the loads of the three devices.

Table 5. Power Loads of a Chromebook, an Intel Compute Stick, and a PoE Thin Client in Edina South View Middle School Media Center

	Chromebook	Intel Compute Stick	10ZiG PoE Thin Client
Average (Watts)	5 - 18	3 - 12	4 - 6
Standby (Watts)	0 - 0.5	0 - 0.5	4

DMTS Offices Lighting Systems. Ubiquiti UniFi LED 2x2 PoE light panels[6] were installed in the Edina DMTS open office area, replacing the 25 original 2x4 T8 troffers with 23 2x2 light panels. Edina school district IT staff installed the lighting systems and a PoE+ network switch powered and controlled these luminaires, providing a maximum of 25 W to each luminaire. Data was collected from the PoE lighting system and the energy use was compared to the calculated energy use of the original 2x4 T8 troffers that were replaced in the space. The original troffers each had three T8 lamps per fixture using 2 electronic rapid start ballast per light fixture. The calculated power load of the original fixtures was about 1850 W. At uniform brightness of 75%, the total load of the Ubiquiti light panels in the office area was measured at 318 W. Since the light panels are dimmable, they were then varied in brightness from 5% to 75% based on each staff person's preference. The total load for this configuration was 167 W. The standby load per light panel was 2 W. Because the light panels were placed in a suspended ceiling and attached by a cable, IT staff could asymmetrically site the panels over each staffer's workspace and improve the delivery of light to each work area. The 5 Ubiquiti wall switches for the lights had a total power load of 18 W. The custom dimmable configuration resulted in a decrease of 90% going from T8s to the PoE light panels.

Discussion

Emerging Technologies

While PoE has been a proven technology for nearly twenty years, the higher power levels provided by UPoE over the last three or four years have only recently allowed for several new applications to be possible. This means that many of the systems and equipment are fairly new to the market and so the range of devices, inventory, and options that are PoE-enabled will be limited until demand increases. In many ways, PoE equipment should be considered emerging technology that is cutting edge and perhaps even bleeding edge. Experience with deployments has shown that some additional development work may still be necessary as equipment and systems are set up and operated under a variety of conditions, uses, and needs. PoE systems require the use of both hardware and software, especially related to the IT network. Software and firmware updates must maintain compatibility amongst all the system components to continually

[6] https://unifi-led.ui.com/

operate properly, this is critical during installation and maintenance. This requires the involvement and commitment of IT staff.

IT and Facilities Support

Since PoE is part of the LAN, IT staff will be needed to maintain the PoE equipment on-site in the same way that they maintain phones, computers, and networked office equipment. As more building systems become networked, IT will gain more responsibility in the operation and maintenance of these systems. Consequently, IT and facilities staff will need to increase coordination. For instance, a PoE light that goes off may not be a simple call to facilities to replace a lamp. The issue may be a network problem that IT will need to diagnose and remedy. As a result, IT departments will need to be prepared and have the capacity to take on roles in building management, operations, and maintenance. As IT services move more and more into the cloud, on-site IT staff will be more amenable to take on these responsibilities. Communications between IT and facilities will need to expand as more equipment becomes networked beyond just PoE.

Networked Equipment

Commissioning. Building systems like lighting and controls require commissioning to be set up to run properly. In the same way, many PoE lighting systems require commissioning by the manufacturer to set up the equipment, sensors, controls, and management software and to program the lighting system operation. IT staff and building occupants are important parts of this process, especially when dealing with lights that are dimmable and color-tunable. IT staff can provide the important role of continuous commissioning services for this equipment that would otherwise be provided by contractors.

IP-Addressable Equipment. Since each PoE device is connected to its port on the network switch, then each device has its own IP-address. IT staff normally oversees and maintains the data and power that is transmitted through each port of the network switches. They perform operations on the network using system dashboards and network management protocols (e.g., SNMP) that allow them to define the specific settings of each networked IP-addressable device and schedule services. IT staff can use these skills and abilities to gain an additional level of control and insight to complement and supplement the management software that might be provided by the PoE equipment manufacturer. Since IT can monitor the power loads and energy use at each port, individual device submetering can now be performed at the network level. Monitoring of PoE systems in this way could fit within the International Performance Measurement and Verification Protocol (IPMVP®)[7] method of exact measurement at the device level, but cost-effectively in comparison with analogous AC-powered systems.

[7] https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp

Baseload or Standby Loads. In addition to the power needed to create the end uses delivered by the PoE devices, there is power demand for other functions provided by the networked devices. This includes such loads as 1) the network switches that connect the PoE devices to the LAN as well as being the PSE to those devices, 2) the network servers that control the switches and communicate with the PDs, and 3) the sensors (occupancy sensors and photocells) and controls (wall switches) that are used to operate the PDs. Since these will likely be continuous loads since all of them will likely be running 24/7 regardless if the PoE devices are operating or not. When the PoE devices are operating, these can be considered as baseloads and when the PoE devices are off, they would be seen as standby loads. These baseloads/standby loads are not unique to PoE systems. Any networked system will have some degree of these loads. For instance, a Wi-Fi-based Digitally Addressable Lighting Interface (DALI) lighting system would need access points, controllers, gateways, sensors, switches, ballasts/drivers, and network servers/switches for network control.

Building System Integration. Since the PoE systems are networked with the IT system, they can be integrated with other building systems that are also on the network. Two examples of building systems integration are being implemented and tested at Edina's SVMS: integration with the school system's BAS and integration with the building's security system.

Working with NAC Mechanical & Electrical, the HVAC contractor for the school district, and Igor whose Nexos system provides the PoE capabilities of the HE Williams lighting system, the PoE lights and sensors were integrated into the Alerton BAS used at SVMS and throughout the district. An Igor BACnet server was installed and configured on the server running the Igor Gateway software. BACtalk was used to communicate between the Igor Gateway and the Alerton Ascent Compass management software. This allowed the BAS to manage and schedule the lights and for the occupancy sensors of the lighting system to communicate and control the classroom's VAV.

For integration with the security system, Parallel Technologies, the contractor that manages the S2 Security system in SVMS, hardwired a cable from a nearby S2 node in the school to an Igor node in the classroom. Using an API, Igor then programmed the lights to respond to a lockdown threat signaled by the security system.

Job Costs and Project Bidding

Because PoE systems use low-voltage DC power, low voltage electrical contractors can install these systems and typically at a lower hourly rate than their line voltage AC counterparts. Some savings in materials costs could also be realized since conduit is normally not required for Ethernet cable where trays are used instead for network cabling. In reality, we did not see this during our efforts to recruit demonstration sites. For two prospective sites, one which was a build out of the second floor of a company's offices and the other the renovation of an entire elementary school, the bids for the PoE lighting systems were tens of thousands of dollars greater than analogous DALI systems. Speaking with the architectural firm that received the bids, three reasons explain the unexpectedly high PoE bids: (1) the electrical contractors used high voltage electrician rates to price the PoE jobs, (2) the contractors had no experience with the PoE systems and bid those jobs higher to cover any exigencies, and (3) the size of the projects required a larger variety of luminaires, many of which were not part of the existing PoE offerings, requiring special orders and higher unit prices. In hindsight, the architecture firm concluded that they should have given the contractors more direction in bidding the lighting system jobs. Bids were performed using the Division 26 Master Specifications Guidelines[8] for electrical and lighting. For the PoE jobs, Division 27 for communications and low voltage should have been specified instead. The winning PoE bid based on Division 27 specs of a later project (the renovation of a high school's administrative offices) was $14,000 less than the bid for the AC-powered DALI system.

Utility Program Considerations

Utility program incentives can help drive the adoption of PoE technologies. Multiple offerings can help designers, engineers, and contractors make these systems more attractive by saving their clients both energy and dollars.

Prescriptive Rebates. Prescriptive rebates are offered by utilities for the purchase of pre-defined energy-saving equipment. A worksheet is typically filled out for the number of devices that meet the guidelines prescribed and the rebate is applied on a per-unit basis. Prescriptive rebates could be developed for specific PoE devices.

PoE lighting systems are by their very nature networked lighting systems. Utilities currently offer rebates for networked lighting controls (NLC), as defined by the DesignLights Consortium (DLC).[9] Prescriptive rebates are offered in multiple ways: (1) per controlled fixture,[10] (2) per Watt of lighting that is controlled,[11, 12] or (3) per square foot of the space that is lit by networked controlled fixtures.[13] Utilities have also shown an interest in luminaire level lighting control (LLLC) and as rebates are introduced for these systems, PoE lighting systems could also benefit from these incentives.

In the same way that rebates are offered for Plug Load ENERGY STAR® equipment, rebates could be offered for PoE equipment such as thin clients, workstations, and displays that have lower power requirements than their analogous line voltage equivalents.

Custom Efficiency Programs. For equipment or processes that do not fit within the requirements of prescriptive rebates, utilities offer custom efficiency programs. To apply for a custom rebate, energy calculations or modeling must be performed to show the kWh or kW that

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[8] https://www.archtoolbox.com/practice/contract-documents/csidivisions.html
[9] https://www.designlights.org/default/assets/File/Lighting%20Controls/DLC_NLC-Technical-Requirements-V3-0.pdf
[10] https://www.coned.com/-/media/files/coned/documents/save-energy-money/rebates-incentives-tax-credits/rebates-incentives-tax-credits-for-commercial-industrial-buildings-customers/commercial-and-industrial-program/program-manual.pdf?la=en
[11] https://www.xcelenergy.com/staticfiles/xe-responsive/Working%20With%20Us/MN-Lighting-Retrofit-App.pdf
[12] https://www.comed.com/WaysToSave/ForYourBusiness/Documents/IndoorNetworkedLightingWorksheet.pdf
[13] https://focusonenergy.com/sites/default/files/Application_PDFs/Networked_Lighting_Controls.pdf

will be saved by the PoE approach. The amount of the rebate will be determined by the utility based on the calculations that are submitted. Custom rebates would be the approach to take: 1) for PoE equipment such as PoE thin clients, workstations, or other technologies that do not yet qualify for prescriptive rebates or 2) processes where PoE systems are integrated with other equipment or building systems for which the savings can only be shown by calculations or modeling. Important considerations for custom programs are labor and O&M (operations and maintenance) savings that the technology provides. It is important to quantify these savings as thoroughly as possible to maximize the rebate and/or ensure the technology qualifies for the custom rebate.

Pay for Performance (P4P) Programs. Pay for Performance (P4P) programs use meter-based quantification of actual energy savings calculated with respect to normalized baselines to determine the utility incentives. These programs have existed in some form for over 25 years[14] and have gained increased attention with California's P4P mandate in 2015.[15] The main issue with P4P programs is performing the M&V cost-effectively and while the advent of smart meters has helped, smart meters are not universally deployed and have a high cost for deployment. Similarly, submetering specifically for M&V can be time-consuming and expensive. As described above, PoE systems are well-suited for P4P programs with the ability to monitor the energy use of IP-addressable devices at the network switch port level. This functionality requires no additional hardware and collecting data can be performed using the network management software or SNMP. P4P programs for integrated PoE systems across several building systems would be particularly effective for attributing energy savings. One potential issue with this approach is the accuracy of the metering equipment (i.e., the networking equipment). Although revenue-grade metering isn't necessarily required, utilities must be made aware of the accuracy limitations of this approach.

Concluding Remarks

This project has demonstrated that PoE technologies that are currently commercially available can provide energy savings, network control, cost-effective end-use energy monitoring, and building system integration. Manufacturers continue to develop and offer more low-voltage DC technologies across a variety of building systems. Low-voltage DC electricity is a viable alternative to power and control building end uses. Navigant Research expects the PoE market in digital building applications to expand at a 14.9% compound annual growth rate over the next 10 years, growing from around $101.5M worldwide in 2019 to $352.9M by the end of 2028 (Wedekind and Maxwell, 2019). This project has shown that to achieve this growth, building staff will need to adapt to the changing O&M needs and responsibilities and contractors and trades will need to gain familiarity with these technologies and systems.

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[14] https://www.nrdc.org/sites/default/files/pay-for-performance-efficiency-report.pdf

[15] https://www.greentechmedia.com/articles/read/california-regulators-take-bold-steps-toward-a-new-energy-paradigm#gs.39lcqq

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