March 27, 2023

REPORT #E23-457

2022 Luminaire Level Lighting Controls Incremental Cost Study

Prepared For NEEA:
Zdanna King, MRE Scientist

Prepared by:
Kate Buck, Senior Manager
Dan Hannigan, Senior Project Manager
Yao-Jung Wen, Senior Staff Engineer

Energy Solutions
449 15th Street
#400
Oakland, CA 94612

Northwest Energy Efficiency Alliance
PHONE
503-688-5400
EMAIL
info@neea.org

Table of Contents

Executive Summary

Luminaire Level Lighting Controls (LLLC), as defined by NEEA, are a type of networked lighting control (NLC) system with integrated sensors and controls in each luminaire that are wirelessly networked, enabling the luminaires within the system to communicate with each other and transmit data. This memorandum provides an estimate of the incremental cost of LLLC.[1] Specifically, the research team estimated the additional equipment and labor costs incurred by installing LED luminaires (also referred to as LED fixtures) with embedded sensors and controls as compared to LED luminaires with no controls.[2] The research team segmented LLLC products into two overarching categories based on their differing features, nominally called "Clever", "Clever-hybrid", and "Smart" systems.

"**Clever**" systems are defined as LLLC which meet basic Design Lights Consortium (DLC) Qualified Products List (QPL) requirements (high-end trim, dimming, occupancy sensors, and photocells) and have "plug and play" fixtures which manufacturers assert require little or no additional programming costs upon installation. "**Smart**" systems include all Clever capabilities but can also analyze and communicate energy and non-energy data to inform decision making processes for a wide variety of Internet of Things (IoT) use cases such as space utilization, HVAC optimization, and retail asset tracking. An emerging product subcategory are **"Clever-hybrid"** systems that fall between Smart and Clever: they include a standalone gateway and provide additional functionality such as energy monitoring, yet lack the full IoT capabilities of a Smart system.

For this year's study, the research team interviewed a total of 12 respondents, including 4 manufacturers, 6 manufacturer representatives, and 2 contractors to collect project cost estimates based on prototypical office buildings. In addition to equipment prices, the team collected different cost components of LLLC, such as programming costs and the cost of gateways. The research team used this data to estimate the total costs for the entire installation and then divided by the assumed number of fixtures to calculate costs on a per fixture basis.

This study found a total incremental cost of $43 per fixture for Clever systems, $55 per fixture for Clever-hybrid systems and $60 per fixture for Smart systems above a standard LED luminaire retrofit without controls. Compared to 2020, this data resulted in a 12% decrease in incremental cost for clever systems, a decrease of 13% for clever-hybrid, and 33% decrease for smart systems. These average incremental costs could potentially be affected or biased by the diverse assumptions the interviewees used when providing the cost estimates and the limited number of unique products included in responses for each LLLC system type. Figure ES-1 depicts the change in the incremental costs of these three system over time between 2017 and 2022.

[1] While the utility industry standard term is "incremental cost," this study is technically collecting data on incremental price because it reflects what a customer would purchase a system for, rather than the incremental cost of the manufacturer to produce the system. However, for industry consistency purposes, the research team has intentionally chosen to use the term "incremental cost."

[2] See Section 2.1 for more details on the base case.

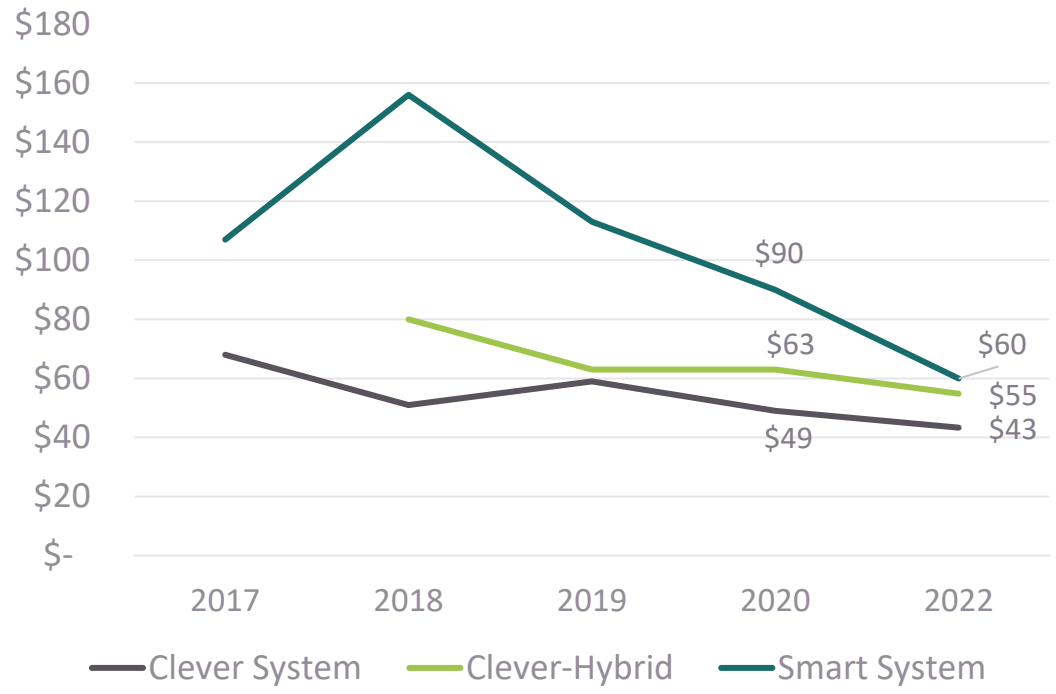

Figure ES-1 Changes in per-fixture incremental costs for Clever, Clever-hybrid and Smart systems between 2017 to 2022.

Since 2017, the more basic Clever systems have seen a 36% decrease in incremental per-fixture costs, while Smart systems have decreased by 44% and Clever-hybrids have decreased by 31% (see Table ES-2). Some annual variability was due to changes in feature sets and components[3], but the overall decreasing trend may be due to increasing competition and economies of scale.

Table ES-2. Changes in incremental cost by system since the previous study in 2020 and the first study in 2017.

	2020-2022	2017-2022
Clever	-12%	-36%
Clever-hybrid	-13%	-31%[4]
Smart	-33%	-44%

Over the course of the research, the incremental cost of Clever, Clever-hybrid and Smart LLLC systems has converged to where the average costs are very similar. This is due, at least in part, to the removal of ongoing subscription or server fees that were common for previous system iterations. Additionally, the pervasiveness of free mobile applications (apps) has made the programming process much more streamlined and efficient. The research team believes that using the incremental cost of

[3] The DLC NLC specification has evolved since its inception in 2016. These specification updates sometimes require new capabilities, such as energy monitoring, thus has a potential to create slight increases in cost.

[4] Clever-hybrid systems were not a category until the 2018 study, so this percentage difference reflects how incremental costs have changed for Clever-hybrid systems since then (and not since 2017).

Clever-hybrid systems as a corresponding incremental cost related to energy savings for Smart systems is justified, as it accounts for the energy-related capabilities of these IoT systems. When comparing incremental cost between system types, it is important to acknowledge that their distinct functionalities create different cost trends over time.

Another key trend the research team observed was that several manufacturers have evolved their product into a “scalable” system, within which there are two or three tiers of offerings. Each tier of the product offering would sit differently on the “scalability” spectrum. As a result, the top-level product could span all the way from a Clever system to a Smart system and, therefore, the line between Clever and Smart has become very blurry. For this study, the determination of Clever, Clever-hybrid, and Smart for such “scalable” products was made at the offering tier.

1. Introduction

1.1 Project Overview

To support NEEA's Luminaire Level Lighting Controls (LLLC) program, Energy Solutions has estimated the incremental cost of three distinct types of LLLC systems, nominally defined by NEEA as "Smart", "Clever", and 'Clever-hybrid"[1] above a standard 2x4 LED troffer fixture. This memorandum outlines the definitions, outreach plan and calculation methodologies implemented for quantifying the comparative cost of Smart, Clever-hybrid, and Clever LLLC systems. Additionally, Energy Solutions collected baseline data and market intelligence on exterior LLLC fixtures. This included the following research objectives (RO):

1. RO1: Estimate the incremental cost between standard and LLLC fixtures. RO1 is to estimate the average incremental cost between a standard fixture and each of the three different levels of LLLC fixtures described in the Executive Summary, including the per-fixture costs of installation and setup.

2. RO2: Across the three levels of LLLC fixtures, estimate and compare the cost components of the energy efficiency capabilities. As described in the Executive Summary, a Clever LLLC system has fixtures with integrated sensors capable of energy efficiency adjustments. The purpose of RO2 is to determine how the manufacturer cost of a Clever fixture's energy efficiency capabilities compares to the price for the same or similar capabilities in a Clever-hybrid fixture and in a Smart fixture.

3. RO3: Research and document the brands and models available in each of the three LLLC levels (Clever, Clever-hybrid, and Smart) and describe the specific features and capabilities of each system that make it fit into one level versus another. NEEA would also like Energy Solutions to identify market trends in availability (e.g., Clever systems exiting the market). These conclusions may be based on quantitative and/or qualitative data.

4. RO4: Explore the current market intelligence for exterior LLLC fixtures. RO4 is meant to gain initial insights into the current installation of exterior LLLC fixtures. What percentage of exterior lighting sales do these currently comprise? Why do some decisionmakers choose these fixtures for their buildings? How can NEEA best assess the changes of incremental costs for these fixtures over time?

1.2 RO3: Classification of LLLC (i.e., Smart vs. Clever vs. Clever-hybrid)

Part of the third research objective was to research and document brands and models available for the LLLC categories and describe the features and capabilities of the system categories. This study focused on fixture-integrated controls that are listed on the DesignLights Consortium (DLC) Networked Lighting Controls (NLC) Qualified Product List (QPL) and classified as LLLC systems. **Clever** systems are defined as LLLCs capable of basic controls including high-end trim, dimming, occupancy sensing, and daylight harvesting, and are 'plug and play' fixtures. **Smart** systems are those that include all Clever capabilities but can also analyze and communicate energy and non-energy data to inform decision making processes for a wide variety of Internet of Things (IoT) use cases. An emerging product subcategory is **Clever-hybrid** systems that fall between Smart and Clever: they include a standalone gateway and provide additional functionality such as energy monitoring yet lack the full IoT

capabilities of a Smart system. Table 1 provides an overview of existing LLLC interior systems on the DLC QPL and their classification as Smart, Clever or Clever-hybrid for the purposes of this study.

Table 1: Interior LLLC systems on the DLC QPL.

Manufacturer	Product	Clever *(n=5)*	Clever-hybrid *(n=8)*	Smart *(n=7)*	In Previous Study (2020)
Acuity Brands	nLight Air®		Yes		Yes
Acuity Brands	nLight®			Yes	Yes
Autani, LLC	Energy Center			Yes	No
Avi-on Labs, Inc.	Avi-on Lighting Control Platform		Yes		No
Cooper Lighting Solutions (formerly Eaton)	WaveLinx Wireless Connected Lighting		Yes		Yes
Digital Lumens	SiteWorx Tune			Yes	Yes
Enlighted Inc	IoT System			Yes	Yes
Current (formerly Hubbell Lighting)	NX Distributed Intelligence		Yes		Yes
J2 Light	SMART BLU	Yes			Yes
Leviton[5]	Intellect Room Controls	Yes			Yes
RCA	Sensor Connect 2.0	Yes			Yes
Lutron Electronics	Vive™ wireless		Yes		Yes
Signify (formerly Philips Lighting)	Interact Pro Foundation	Yes			Yes[6]
Signify (formerly Philips Lighting)	Interact Pro Advanced		Yes		No
Signify (formerly Philips Lighting)	Interact Pro Enterprise			Yes	No
Signify (formerly Philips Lighting)	EasySense		Yes		Yes
RAB	Lightcloud			Yes	Yes
Xeleum	Xi-Fi Lighting Controls System	Yes			Yes
Current (formerly GE Current)	Daintree EZ Connect		Yes		Yes[7]
Current (formerly GE Current)	Daintree Networked			Yes	Yes

[5] Leviton is not DLC listed, but is included because it has the attributes important to NEEA's definition of LLLC.

[6] This system was listed in the previous years' study as "SpaceWise," which has evolved into and rebranded as the Interact Pro. Interact Pro is scalable at three tiers: Foundation, Advanced, and Enterprise. Foundation is the equivalent of SpaceWise. Based on the system type classification determined with NEEA at the outset of this research, we continued to classify Interact Pro Foundation as a Clever system. However, due to its scalability, we recommend classifying Interact Pro Advanced as Clever-hybrid and Interact Pro Enterprise as Smart.

[7] The Daintree system included in the 2020 study was a system without any variations and was classified as a Smart system. The system has since evolved into a "scalable" system with three tiers: Daintree One, Daintree EZ Connect, and Daintree Networked. Daintree One does not seem to meet all the DLC requirements. Daintree EZ Connect met all the basic DLC technical requirements, though Current was still in the process of getting it qualified for DLC listing. Daintree Networked was DLC listed. Based on their capabilities and feature sets, we classified Daintree EZ Connect as a Clever system and Daintree Networked as a Smart system.

This year, the program team also explored market intelligence for exterior LLLC fixtures as part of the fourth research objective. Table 2 shares a list of exterior LLLC manufacturers and brands approved by the DLC QPL in the fall of 2022.

Table 2: Exterior LLLC systems on the DLC QPL.

Manufacturer	Brand Name
Acuity Brands	Acuity Controls
Cooper Lighting Solutions (formerly Eaton)	WaveLinx
Current	Daintree Enterprise
Current	NX Lighting Controls
Linmore LED Labs	UltraLink
RAB Lighting	Lightcloud

2. Methods

This section provides an overview of the definitions, methods, and assumptions utilized in identifying the incremental cost of each cost component of fixture-integrated controls.

2.1 Definition of Total Incremental Cost

The total incremental costs of Smart, Clever, and Clever-hybrid systems were defined as the difference between the respective costs of their controls, gateways, and programming needs minus the expenses of purchasing an LED fixture without controls. Specifically, the base case (no controls) was defined as a retrofit scenario in which 2x4 fluorescent troffers were replaced with LED luminaires. While the reader will also notice an incremental fixture cost that is calculated by subtracting the cost of the LED fixture without controls from the cost of the LED fixture with controls, the important finding for this study is around the total incremental cost of the LLLC systems.

2.2 Cost Components

The total cost of each system is composed of multiple types of component costs, including equipment, licensing, and labor related expenses, in addition to optional service support and asset tracking (see Table 3).

The cost of Clever systems was made up of the following components:

- Cost of an LED fixture with an integrated sensor
- Labor cost of controls installation and programming
- Tools required to install and commission the system (configuration tools)
- Support services (e.g. technical phone support, on-site programming, sensor layout and tuning)

In addition to the components of Clever systems, the cost of Clever-hybrid and Smart systems may also include the following, depending on the specific controls system and the package purchased by the customer:

- Gateway(s)
- One-time or ongoing licensing fees for the controls network
- Software one-time and ongoing subscription fees

For Clever-hybrid and Smart systems, a customer's specific purchase package may vary widely due to the number of options available and the customer's individual needs. This may include ongoing subscription fees or value-added services such as asset tracking. While this information was collected where available, it is not included in the study since it is not related to the energy savings aspects of LLLC products.

Table 3: Typical components contributing to the cost of LLLC products.

Cost Type	Cost Component	Applicable to this Product Type?		
		Clever	Clever-hybrid	Smart
Equipment	Incremental Fixture Cost*	Yes	Yes	Yes
	Gateway*	No	Possible	Yes
	Configuration tool	No	Possible	Possible
Licensing	One-time or On-Going Cost	No	Possible	Possible
Labor	Commissioning (aka Programming)	Yes	Yes	Yes
Optional	Service support, Asset tracking	No	Possible	Possible

2.3 Data Collection Methods

The research team conducted outreach with twelve market actors from different companies, including four manufacturers, six manufacturer representatives and two contractors (see Table 4). Those interviews generated incremental cost estimates for seven unique LLLC products.

Table 4. Market actors interviewed and the LLLC products featured in their responses.

Market Actors Interviewed *(n=12)*	Market Actors' Company	LLLC Products
Contractor *(n=2)*	Eco Engineering	Enlighted IoT
	EC Company	Acuity nLight
Manufacturer's Representative *(n=6)*	Apex Lighting Systems / Connecticut	Signify Interact Pro Advanced
	ESS / Esposure Lighting	Current Daintree EZ Connect
	Reflex Lighting	Cooper Wavelinx Lite
	Lighting Group/Seattle	Acuity nLight
	CAL Lighting/California	Enlighted IoT
	Lighting Affiliates	Acuity nLight
Manufacturers *(n=4)*	J2Light	J2Light
	Signify	Signify EasySense
	Acuity	Acuity nLight
	Enlighted	Enlighted IoT

It became apparent during the interview process that fewer Clever systems were available in the market in 2022, resulting in only one Clever system being included in our estimates, while we were able to secure responses about four Clever-hybrid systems and seven Smart systems (see Table 5).

Table 5. Number of interview responses per product and by LLLC system category.

LLLC Products	Clever *(n=1)*	Clever-hybrid *(n=4)*	Smart *(n=7)*
J2Light	1	-	-
Current Daintree EZ Connect	-	1	-
Cooper Wavelinx Lite	-	1	-
Signify EasySense	-	1	-
Signify Interact Pro Advanced	-	1	-
Acuity nLight	-	-	4
Enlighted IoT	-	-	3

2.4 Calculation Methodology

We calculated the incremental (and other) costs by taking an average of all estimates for that category. If there were major outliers which skewed the results, we identified or removed them when there was not a clear explanation of the wide variance in cost. LLLC cost types (such as equipment, licensing, etc…) and the components of each type (such as gateways, fixtures, configuration tools, etc…) can be found above in Table 3.

To ensure uniformity in estimating costs, all costs were calculated assuming a standard building and space type, with assumed values for building size, fixture and gateway density, and labor costs. These assumptions are detailed in Table 6 for each system category.

Table 6. Model inputs (building prototype, installation, and labor assumptions) for Clever, Clever-hybrid and Smart systems and their sources.

Model input	Source	Clever & Clever-hybrid	Smart
Lit space	Input	40,000 ft^2	100,000 ft^2
Fixtures per building	Interviews	367 fixtures	917 fixtures
Hourly rate for controls installation and commissioning	LBNL 2015 (Adjusted)	$50	$100
Gateways per building	Interviews	2 gateways	5 gateways
Square footage per fixture	Calculated	109 ft^2	
Configuration tools per building	Interviews	0 to 1 tools	
Room (or group of light) square footage	DEER Large Office Building Prototype	350 ft^2	

The total project cost for each system type was calculated as follows:

$$Total\ Project\ Cost = (LLLC\ fixture\ cost + labor\ cost\ per\ fixture + gateway\ cost\ per\ fixture) \times number\ of\ fixtures$$

Also note that while most products included configuration tools, they were exclusively app-based and free, and thus were not included in the list of costs in the results below.

3. RO1 & RO2 Results: Incremental Costs of LLLC Systems

3.1 Incremental Cost of a Clever LLLC Fixture

The total incremental cost of a Clever LLLC fixture was about $43 per fixture (see Table 7). When we further split the total incremental cost by the programming labor these fixtures need, the gateways needed to support them, and the fixtures themselves, close to one-fifth of the incremental cost was due to programming expenses for Clever LLLC fixtures (see Figure 1 below).

Table 7. Cost components and per-fixture cost of the Clever LLLC product.

	Cost Breakdown
Individual Cost Components	
LED Fixture Without Controls ($/fixture)	$95.00
LLLC Fixture ($/fixture)	$130.00
Gateways ($/gateway)	$0.00
Average Per-Fixture Costs	
Incremental Fixture Cost	$35.00
Programming Cost	$8.33
Gateway Cost	$0.00
Total Incremental Cost	**$43.33**
Total Project Costs Based on 40,000 Sq. Ft. Building	
Total Project Cost	$50,768.33
Total Project Cost (Per Sq. Ft.)	$1.27

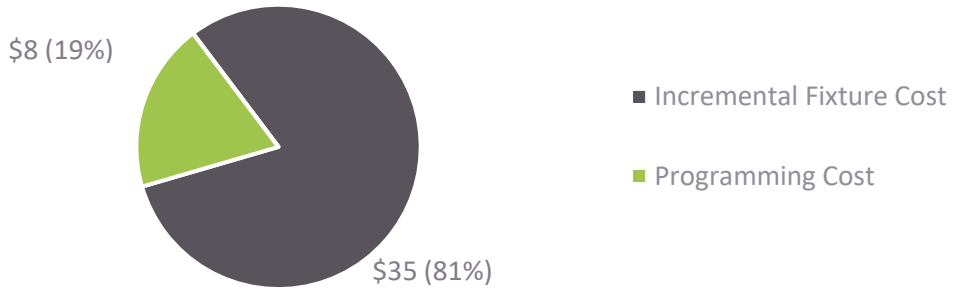

Figure 1. The total incremental cost breakdown of a Clever LLLC fixture, in which gateways were not required.

3.2 Incremental Cost of Clever-Hybrid LLLC Fixtures

As shown in Table 8 below, the average total incremental cost of four Clever-hybrid estimates was about $55 per fixture, with a range from about $51 to $67. Two Clever-hybrid system providers indicated a gateway was required for the lighting scenario, while the other respondents did not, and the costs were highly divergent with one respondent quoting $500 per gateway and another estimating $1500 for a gateway. Table 8 below summarizes the Clever-hybrid cost estimates provided by respondents, including both the cost of components and overall project fees. Additionally, Figure 2 shows the breakdown of the total incremental cost, with about 6% of $55 going towards programming expenses, 7% going towards purchasing gateways, and 87% for the fixture itself.

Table 8. Cost components and per-fixture cost estimates of Clever-hybrid LLLC products[8].

	Average *(n=4)*	Min	Max
Individual Cost Components			
LED Fixture Without Controls ($/fixture)	$97.50	$60.00	$140.00
LLLC Fixture ($/fixture)	$145.00	$110.00	$185.00
Gateways ($/gateway)	$500.00	$0.00	$1,500.00
Average Per-Fixture Costs			
Incremental Fixture Cost	$47.50	$45.00	$50.00
Programming Cost	$3.38	$0.50	$8.33
Gateway Cost	$3.96	$0.00	$13.33
Total Incremental Cost	**$54.83**	$50.50	$66.67
Total Project Costs Based on 40,000 Sq. Ft. Building			
Total Project Cost	$55,906.33	$40,553.50	$75,846.67
Total Project Cost (Per Sq. Ft.)	$1.40	$1.01	$1.90

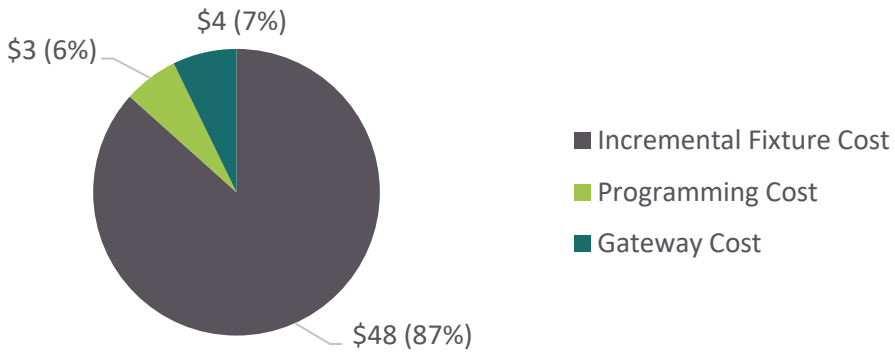

Figure 2. The total incremental cost breakdown of Clever-hybrid LLLC fixtures.

[8] Systems are sold as a package, so the total minimum or maximum cost of each incremental component may not add up to the total minimum quote provided by an individual market actor.

3.3 Incremental Cost of Smart LLLC Fixtures

As shown in Table 9 below, the average total incremental cost for seven Smart LLLC fixtures was $60 per fixture, with a range from $44 to $92. Again, this wide variation was likely due to the range of node and gateway costs provided by interviewees. Smart system gateways cost an average of $834 each, but varied significantly from a minimum of $288 to a maximum of $2,000. Programming times for Smart systems were also highly variable, with the average at about $3 per node (down from $4 in the previous 2020 study). Like with Clever and Clever-hybrid systems, most Smart systems were forgoing any subscription, server, or ongoing licensing fees.Table 9 below describes the cost components and overall project cost for a Smart system installed in a 100,000 square foot building.

Table 9. Cost components and per-fixture cost estimates of the Smart LLLC products[9].

	Average (n=7)	Min	Max
Individual Cost Components			
LED Fixture Without Controls ($/fixture)	$91.50	$75.00	$115.00
LLLC Fixture ($/fixture)	$143.17	$119.00	$180.00
Gateways ($/gateway)	$834.00	$0.00	$2,000.00
Average Per-Fixture Costs			
Incremental Fixture Cost	$51.67	$44.00	$65.00
Programming Cost	$3.11	$0.04	$8.33
Gateway Cost	$5.19	$0.00	$18.75
Total Incremental Cost	**$59.97**	$44.04	$92.08
Total Project Costs Based on 100,000 Sq. Ft. Building			
Total Project Cost	$138,897.11	$109,161.21	$189,895.42
Total Project Cost (Per Sq. Ft.)	$1.39	$1.09	$1.90

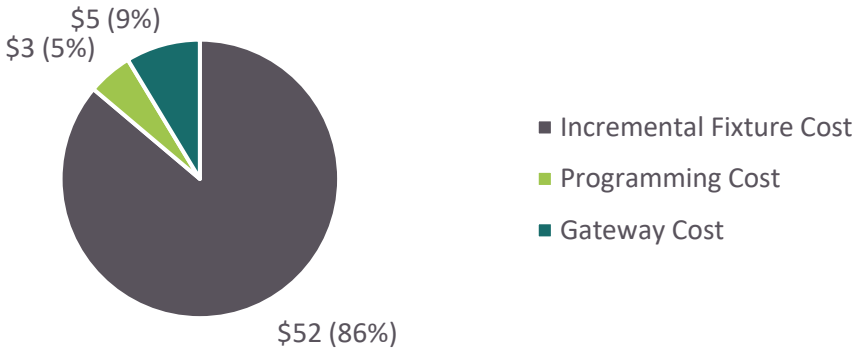

Figure 3. The total incremental cost breakdown of Smart LLLC fixtures.

[9] Note that because systems were sold as a package, the total minimum or maximum cost of each incremental component may not add up to the total minimum quote provided by an individual market actor.

3.4 Comparison of Incremental Cost Breakdowns across LLLC System Types

When we compared the total incremental cost breakdowns across LLLC system types, programming expenses were slightly higher for Clever systems, and programming and gateway expenses were fairly similar for Clever-hybrid and Smart systems (see Figure 4). Fixture controls themselves were progressively more expensive as their functionality increased by system type.

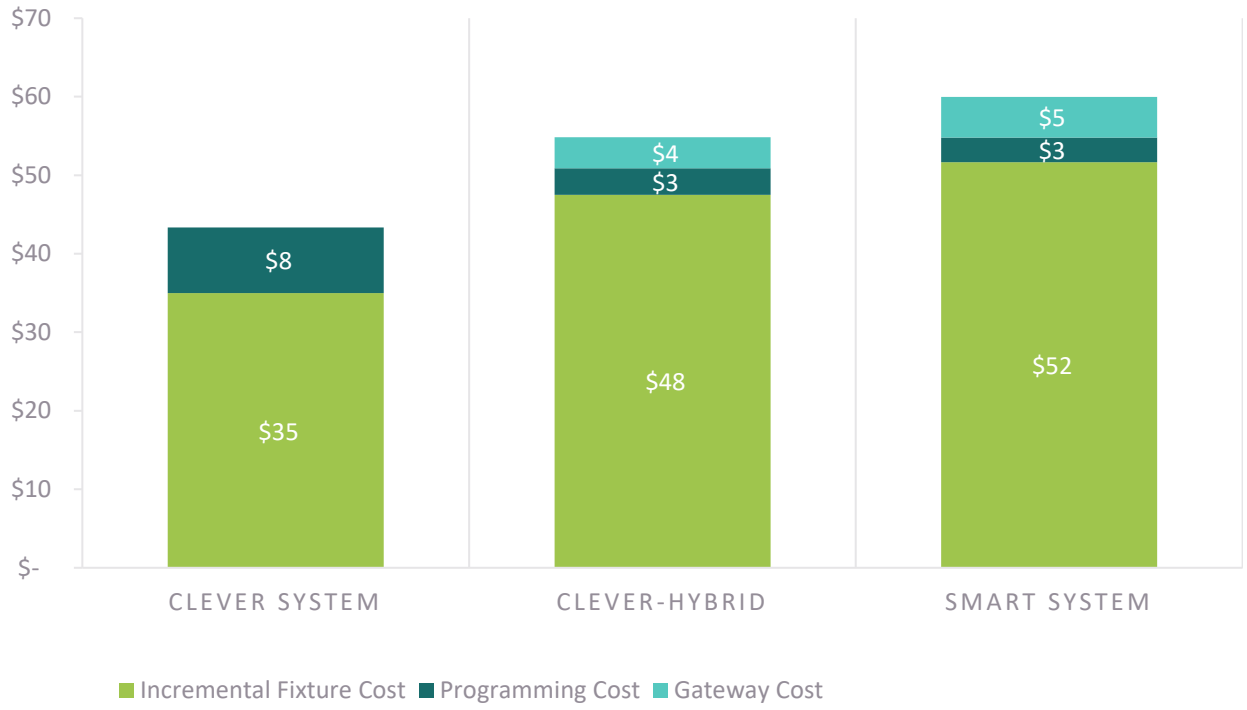

Figure 4. Total incremental cost breakdown of Clever, Clever-hybrid, and Smart LLLC fixtures.

4. RO3 & RO4 Results: Market Trends of Interior and Exterior LLLC Systems

4.1 Clever LLLC Systems May Be Exiting the Market

During the interviews, we asked respondents to list the brands and models they installed, sold, or represented in order to choose a specific product for further cost estimates. While many respondents provided examples of Clever-hybrid and Smart systems, only one shared a product from our Clever LLLC product list. While the overall sample size is small, this may indicate that Clever systems are becoming less popular as Smart systems improve to provide more functionality at a lower incremental price.

4.2 Improvements in Configuration Tools and Software have Contributed to Decreased Cost

Improvements in configuration tools and software have streamlined the process of installing and utilizing LLLC systems, and the permeation of cell phone applications (apps) to complete commissioning has also led to a decrease in cost for these components over time. Almost all of the respondents (10 out of 11) indicated an app (or other software tool) was available for free. Total programming time per project was primarily dependent on the individual system being installed, rather than if the LLLC system was Clever, Clever-hybrid or Smart.

4.3 Ongoing Subscription Fees may have Disappeared from the Market

None of the interview respondents indicated there were either ongoing, or one-time fees to enable basic system functionality. However, the scope of the interview questions did not address if additional fees might be required to unlock or enable specific functions that were not required for basic system operation.

4.4 All of the Respondents were Installing, Selling, or Manufacturing Exterior LLLC Systems

All of the respondents indicated they had sold or installed exterior parking lot fixtures with LLLC. The percentage of exterior LLLC projects (relative to non-LLLC projects) was highly variable, spanning between 10% and 80% of projects sold or installed.

4.5 Exterior LLLC End Customers Most Motivated by System Adaptability and Savings Potential

The most noted motivating factor for clients installing exterior LLLC projects was system adaptability, or the ability to update or change the lighting controls' schedule and configuration in the future. The second most noted factor was the ability to save more energy and monitor the system to determine additional energy saving opportunities. Utility rebates, as well as safety, were also mentioned by several interviewees. Two respondents indicated that exterior LLLC were required by building codes in certain regions (e.g., California).

5. Potential Limitations

During the data collection and analysis period, the research team observed that respondents' diverse project assumptions, as well as the limited number of products included in cost estimates, could have impacted the accuracy of the incremental cost estimates.

The interviewees used diverse assumptions to estimate the number of luminaires required for a project, which could have affected many cost components. Even though the research team specifically instructed the interviewees to estimate the project size using 2x4 fluorescent troffers or panels for a given square footage, responses still varied widely with respondents estimating that each luminaire could light an area between 67 and 200 square feet. This wide range number of luminaires would in turn affect the interviewees' estimates on system programming hours and costs, and perhaps even more impactfully, the number of gateways needed for a project.

Also, while the research team targeted a set number of stakeholders to collect cost data from, they tended to provide estimates on a limited range of the available products. This resulted in only one product type for Clever LLLC systems and two product types for Smart LLLC systems. While having multiple data points for the same products certainly helped even out the cost variability for Smart LLLC

products, drawing estimates from a small number of products may not capture the full range of pricing in the market.

6. Conclusions

6.1 RO1 & RO 2: Incremental Costs Have Decreased Over Time

Overall, incremental costs have dropped dramatically across all three LLLC System types from when they were first studied in 2017 (for Clever and Smart LLLC systems) and 2018 (when Clever-hybrid emerged as a category) (see Table 10). Smart LLLC systems have seen the largest overall decrease of 44% of cost, from an initial $107 in 2017 to $60 in 2022 (see Tables 10 & 11 & Figure 5). Clever LLLC systems have followed close behind with an overall 36% drop in cost and Clever-hybrid have decreased by 31%. Recent drops are responsible for most of the Smart LLLC systems' changes in cost, reflecting a $30 reduction in incremental cost (versus changes under $10 in the other categories that are more on par with the year to year differences seen over time in these studies). The cost decline for all three system types could have been even more significant if adjusted for inflation, but as inflation adjustments have not been made for prior incremental cost studies, we decided to keep the results as comparable as possible by not including them here.

Table 10. Changes in incremental cost by system since the previous study in 2020 and the first study in 2017.

	2020-2022	2017-2022
Clever	-12%	**-36%**
Clever-hybrid	-13%	**-31%**[10]
Smart	-33%	**-44%**

Table 11. Average incremental per-fixture costs between 2017 and 2022.

	2017	2018	2019	2020	2022
Clever	$68	$51	$59	$49	$43
Clever-hybrid	N/A	$80	$63	$63	$55
Smart	$107	$156	$113	$90	$60

[10] Clever-hybrid systems were not a category until the 2018 study, so this percentage difference reflects how incremental costs have changed for Clever-hybrid systems since then (and not since 2017).

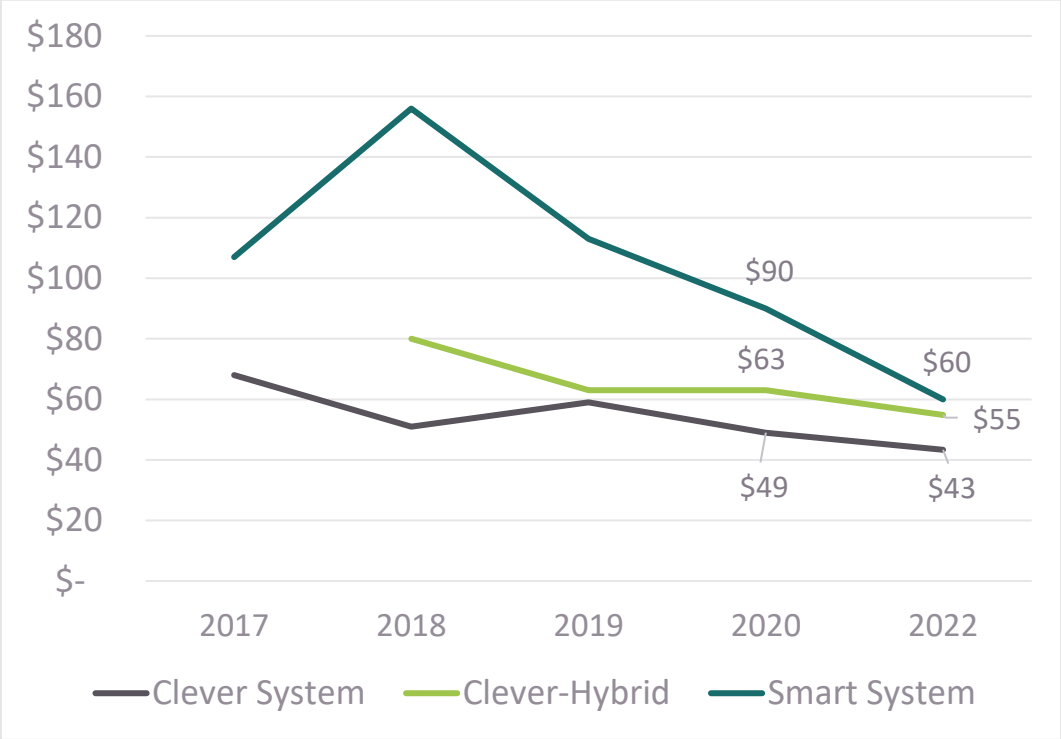

Figure 5. Changes in per fixture incremental costs for Clever, Clever-hybrid, and Smart systems between 2017 to 2022.

This decreasing trend in incremental costs may be due to the following factors:

- Increasing competition
- Economies of scale
- Wider availability of drivers that supports power and communication required for LLLC nodes
- Manufacturers gaining proficiency in optimizing product design to reduce cost

Smart systems have seen the most significant decrease in the incremental cost. This could be partly due to the commissioning interface being moved to mobile apps, which may reduce cost in software maintenance, simplify the commissioning procedure, and eliminate the need for a dedicated server. Also, increasingly advanced features that were previously unique to a few systems are now a required capability in meeting the DesignLights Consortium's product qualification technical requirements, thereby driving down the cost premium.

6.2 RO2: It is Appropriate for NEEA to Use the Clever-hybrid Incremental Cost for Cost-Effectiveness Calculations

Over the course of the research, the incremental cost of Clever, Clever-hybrid and Smart LLLC systems has converged to where the average costs are very similar. This is due, at least in part, to the removal of ongoing subscription or server fees that were common for previous system iterations. Additionally, the pervasiveness of free mobile applications (apps) has made the programming process much more streamlined and efficient. The research team believes that using the incremental cost of Clever-hybrid systems as a corresponding incremental cost related to energy savings for Smart systems is justified, as it accounts for the energy-related capabilities of these IoT systems. When comparing incremental cost between system types, it is important to acknowledge that their distinct functionalities create different cost trends over time.

6.3 RO3: LLLC Systems have Evolved

LLLC systems have changed since we first started doing this kind of study six years ago in terms of incremental cost, programming support needed, configuration tools, servers needed, subscription fees, the scalability of products (the same product can be Clever or Smart, depending on the options that the customer chooses) and general availability of system types (ie, Clever, Clever-hybrid, and Smart). Incremental costs have dropped and narrowed between system types. Configuration tools and servers are no longer necessary, with many systems sporting free apps that set up, monitor, and control lighting systems over time. Subscription and one-time fees for lighting software have seemed to exit the market, and lower functionality Clever systems are becoming less utilized by the people who represent, sell, and install them.

6.4 RO4: Exterior LLLC was Utilized by the Same Market Actors and Appealed to Customers

All of the respondents also sold, represented, or installed exterior LLLC as well, with some noting that they used it in up to 80% of their exterior projects in the last year. Customers were motivated to purchase exterior LLLC by its adaptability, energy savings, energy monitoring that might lead to additional energy savings, and rebates available from utilities.

7. Recommendations for Future Study

As NEEA's LLLC program needs evolve, the research team suggests the following for future studies:

- Consider changing the current methodology to a sample building layout and specification to standardize project cost estimate and prevent interviewees from using diverse assumptions, to estimate the required number of luminaires.
- Further assess the functional differences (from a consumer perspective) between Clever, Clever-hybrid, and Smart LLLC systems, especially given that several manufacturers are now offering "scalable" products with different tiers spanning from Clever to Smart.
- Consider identifying whether it is appropriate to increase the sample size of this study to improve certainty.
- Consider targeting a set number of responses and unique systems for each system type, as opposed to an overall number of surveys, to ensure sufficient sample of unique products for each system type.