January 7, 2021

REPORT #E21-415

2020 Luminaire Level Lighting Controls Incremental Cost Study

Prepared For NEEA:
Jennifer Stout, Project Manager, Market Research & Evaluation

Prepared by:
Teddy Kisch, Sr. Manager, New Product Delivery
Kate DoVale, Project Manager

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

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

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 report 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 integrated (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 and price points, nominally called "clever" 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 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.[3]

For this year's study, the research team reviewed secondary data sources and interviewed a total of 16 manufacturers and manufacturer representatives to collect 19 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 $49 per fixture for clever systems, $63 per fixture for clever-hybrid systems, and $90 per fixture for smart systems above a standard LED luminaire retrofit without controls. The analysis also showed that between 2019 and 2020, there was a 17% decrease in incremental cost for clever systems, no change for clever-hybrid, and a 20% decrease for smart systems. When considering clever and clever-hybrid systems as a broader single category, there was 7% overall decrease. However, there is a wide range in prices and pricing approaches, including ongoing subscriptions for smart systems.

Table ES-1 and Figure ES-1 depict the change in incremental cost of these three system types between 2017 and 2020. As shown, over these four years, the incremental cost of clever systems fell 28%, clever-hybrid fell 21%, and smart fell 16%.

---

[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 detail on the base case. Also, this year, for the first time, the research team compared the cost of installing LLLC luminaires with the cost of installing luminaires with controls meeting minimum code requirements. These results are provided in Section 3.

[3] CREE's SmartCast product was categorized as a clever-hybrid system in the 2018 study. Based on discussion with the NEEA team, this product was re-categorized as a clever system for the 2019 study.

Table ES-1. Incremental per-fixture cost each study year, and percent change between 2017 and 2020.

	Incremental Cost (per fixture)				
Year	**2017**	**2018**	**2019**	**2020**	**Percent Change 2017-2020**
System	Average	Average	Average	Average	Average
Clever	$68	$51	$59	$49	-28%
Clever-Hybrid	N/A	$80	$63	$63	-21%
Smart	$107	$156	$113	$90	-16%

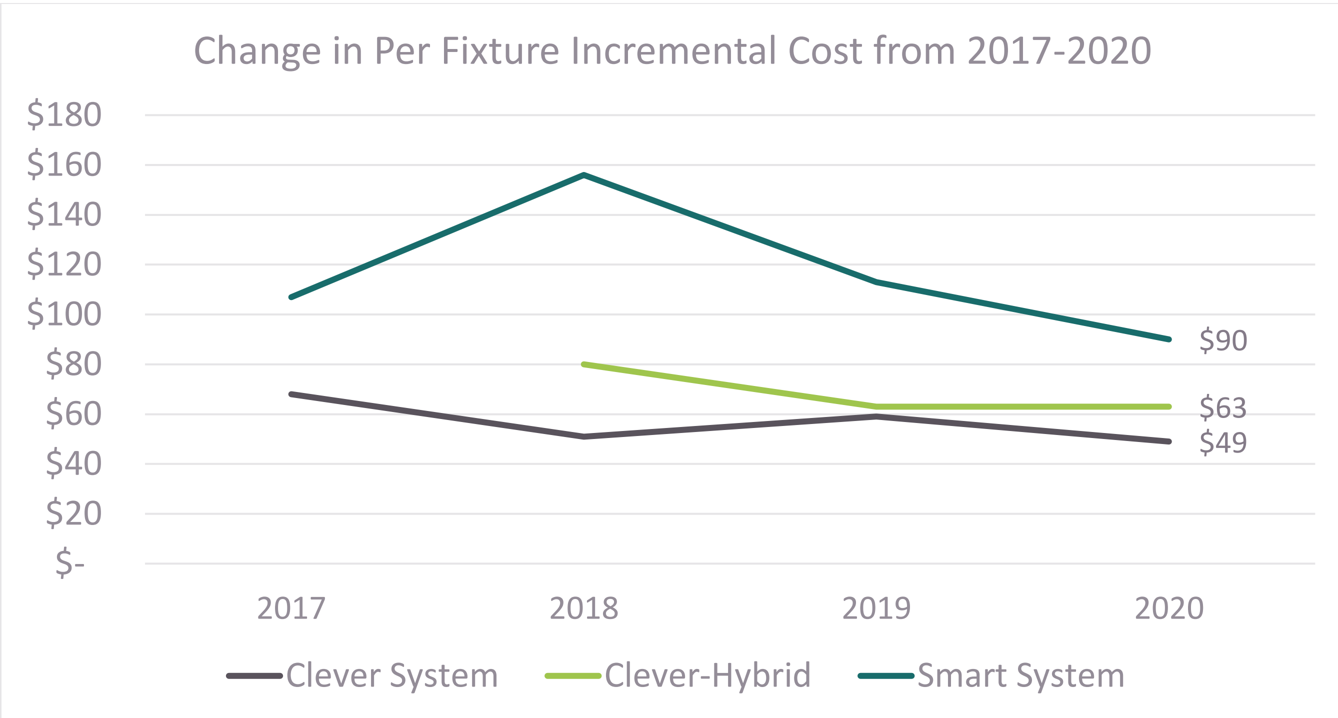

Figure ES-1 Changes in per fixture incremental costs for clever, clever-hybrid and smart systems between 2017 to 2020.

Since 2017, the more basic clever systems have seen a 28% decrease in incremental per fixture costs, with some annual variability due to changes in feature sets and components.[4] This generally decreasing trend may be due to increasing competition and economies of scale. Since 2018 when clever-hybrid systems entered the market, they have seen a 21% decrease in incremental per-fixture cost. This smaller decrease is likely due to the greater number of product feature sets that create consumer value.

The average price for more complex, smart systems has oscillated but shows an overall decrease in costs over time. This oscillation may be due to the continued addition of incremental feature packages and capabilities that the smart systems can enable. Smart systems remain more expensive than their clever-hybrid counterparts, and their value proposition is likely focused on increasing value from non-energy benefits.

[4] The DLC specification for NLC has evolved since its inception in 2016. These specification updates sometimes include new capabilities, such as energy monitoring, and thus have the potential to create slight increases in cost.

The greater costs of smart systems are primarily due to the supplemental, value-added services provided beyond energy savings. Most clever-hybrid systems lack the major non-energy benefits provided by smart systems. While it is difficult to determine the additional energy savings that smart systems achieve over clever-hybrid systems, there was consensus among respondents that the incremental step to smart systems is driven primarily by non-energy features.

As a proxy for the incremental cost of just the energy saving capabilities of smart systems, the research team believes using the incremental cost of clever-hybrid systems is a sound approach. As described above, clever-hybrid systems fall between smart and clever: they include a standalone gateway and provide additional functionality such as energy monitoring but do not have the full IoT capabilities of a smart system. An alternate approach could be to attribute a fraction (10-25%) of the price difference between clever-hybrid and smart systems to account for supplemental features that increase energy savings. When comparing incremental cost between system types, it is important to acknowledge that their distinct functionalities create different cost trends over time.

1. Introduction

LED luminaires are increasingly prevalent in commercial applications and are predicted to comprise over 70% of the linear lighting fixture market by 2030.[5] The long lifetime and low overall wattages of LED luminaires (also referred to as LED fixtures) create a stranded savings opportunity because, once installed, it is highly unlikely they will be retrofitted with controls during their remaining useful life, thus eliminating the opportunity for deeper energy savings for roughly ten years.

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. LLLC provide control capabilities for each fixture, such as occupancy and vacancy sensing, daylight harvesting, high-end trim, continuous dimming, and combinations of these capabilities. The granularity of fixture-level detection and control afforded by LLLC maximizes the potential for customization of lighting services and deep energy savings.

Key adoption barriers for LLLC include the lack of customer or contractor awareness and the incremental cost of installing LLLC fixtures with integrated sensors and controls instead of standard LED fixtures, despite the significant additional savings opportunities and non-energy benefits. This report provides a comparison of the incremental cost of both clever and smart systems relative to an LED luminaire base case.

LLLC systems can be informally classified as "clever" or "smart". **Clever** systems are defined as LLLC which meet basic Design Light 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 IoT use cases such as space utilization, HVAC optimization, and retail asset tracking.

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. For the purposes of this study, clever-hybrid systems are defined on the DLC's Qualified Product List as LLLC that also have energy monitoring capabilities, unless specifically identified otherwise.[6] Table 1 shows the classification of each LLLC included in this study by system type.

---

[5] Navigant. 2014*. Energy Savings Forecast of Solid-State Lighting in General Illumination Applications*. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energysavingsforecast14.pdf

[6] For example, while Philips Spacewise and Easysense products technically have energy monitoring capabilities, the energy monitoring is located within each fixture and so it is not practical to conduct monitoring for an entire site. Thus, the research team has categorized it as a clever system.

Table 1. The "clever", "clever-hybrid" and "smart" LLLC offerings examined in this study, as listed on the DLC qualified products list, are indicated with a "yes". Blank cells indicate that the manufacturer does not have an LLLC offering of the specified type.

Manufacturer	Product	Clever	Clever-Hybrid	Smart
Acuity Brands	nLight Air®		Yes	
Acuity Brands	nLight®			Yes
Avi-on	Avi-on Lighting Control Platform		Yes	
Cree, Inc.	SmartCast® Technology	Yes		
Digital Lumens	Siteworx			Yes
Eaton	WaveLinx		Yes	
Enlighted Inc	Enlighted			Yes
GE Current	Daintree			Yes
Hubbell Lighting	NX Distributed Intelligence			Yes
J2 Light	Smart Blu	Yes		
Lutron Electronics	Vive™ wireless		Yes	
RAB	Lightcloud			Yes
Signify (Philips Lighting)	SpaceWise	Yes		

2. Methods

This section provides an overview of the definitions, methods, and assumptions utilized in identifying the incremental cost on a per-fixture basis of each cost component of LLLC.

2.1 Definition of Incremental Cost

For the purposes of this analysis, the research team defined incremental cost as the difference between the cost of purchasing and installing an LED fixture with LLLC functionality and one without LLLC functionality. Specifically, the base case is defined as a retrofit scenario in which 2 x 4 fluorescent troffers are replaced with LED luminaires with no controls.[7] The incremental cost of "smart" and "clever" systems is defined as the difference between their respective costs and the base case.

2.2 Cost Components

Clever and smart system components are typically differentiated by smart systems' need for additional network infrastructure. The cost of clever systems is made up of the following components:

- Cost of an LED fixture with an integrated sensor
- Labor cost of controls installation and programming[8]
- 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
- Server cost or hosting fee for data storage
- 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.

[7] This year, for the first time, the research team also compared the cost of installing LLLC luminaires with the cost of installing luminaires with controls meeting minimum code requirements. These results are provided in Section 3.

[8] Programming involves configuring the control system so that fixtures, switches, and gateways can accurately communicate with each other and send and receive signals.

Table 2. The 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
	Configuration Tool[9]	Yes	Yes	Yes
	Gateway	No	Yes	Yes
	Asset Tracking	No	No	Yes
Licensing	One-time or On-Going Cost	No	Yes	Yes
	Software Subscription Fee	No	No	Yes
Labor	Programming	Yes	Yes	Yes
	Support Services	Yes	Yes	Yes

2.3 Data Collection Methods

The research team reviewed secondary sources and interviewed ten manufacturers and six manufacturer representatives. Respondents provided estimated costs for equipment and labor components of LLLC projects based on prototypical office buildings. In all cases, the research team explicitly asked respondents for the cost to the end use customer.[10] As shown in Table 3, the 16 respondents provided cost information for 19 projects of different LLLC system types representing 13 unique control system brands.

Table 3. Respondents' project cost estimates by LLLC system type and unique brand.

System Type	Responses	Brands
Clever	4	3
Clever-Hybrid	6	4
Smart	9	6
TOTAL	19	13

2.4 Data Analysis Methods

The research team asked respondents to provide price estimates broken out by each cost component, for all systems. Reponses for each fixture included the minimum, maximum, and average (mean) cost estimate on a per fixture basis.

The research team estimated per-fixture costs using two single-story, square-shaped prototypical office buildings: a 40,000 square foot office building for clever systems and a 100,000 square foot office building for smart systems. The difference in prototype building size is due to the distinct applications of the two systems. Clever systems are primarily intended for smaller office buildings that do not have dedicated facilities managers, and for organizations that are less likely to purchase a more expensive

[9] While early versions of clever and smart systems included standalone configuration tools, virtually all systems now use a smart phone app for configuration. A physical configuration tool is still an option in half of the systems, although it appears that phone-based apps are the tool of choice.

[10] In some cases, manufacturer respondents only had costs for distributors. In this case, the research team assumed a 15% distributor markup and an additional 15% contractor markup (a 32.25% total markup).

smart system; smart systems are typically purchased by large organizations seeking to leverage the data collected by the lighting controls system for a variety of IoT use cases such as space utilization, asset tracking and energy monitoring. Tables 4 and 5 provide an overview of the assumptions for each building prototype used to calculate costs.

The team based labor cost estimates on respondents' estimates of programming time and cost. If no labor cost data was available for that system, the team based labor estimates on a 2015 Lawrence Berkeley National Laboratory (LBNL) study which found values ranging from $30 to $100 per hour. Therefore, the team assumed labor rates of $50 per hour and $100 per hour for programming clever and smart systems respectively where no data is available. The $50 per hour rate for clever systems reflects their ability to be programmed by facilities managers or contractors, while the smart systems typically require programming by manufacturers or manufacturers' representatives, which typically have higher fee structures. The assumption that LLLC systems operate for 5 years is derived from the DLC requirement that LED luminaires and NLCs must have a minimum warranty of 5 years. The estimated operational lifetime is reflected in ongoing annual fees, applicable to some smart systems. Total building costs were divided by the assumed total number of fixtures to calculate per fixture cost estimates.

Table 4. Building prototype, installation, and labor assumptions (clever and clever-hybrid).

Value	Meaning	Source
40,000	Square feet of lit space	Input
85	Square feet per fixture	LBNL 2015
471	Fixtures per building	Calculated
5	Years of Operation	DLC QPL Requirements
$50	Hourly rate for programming by facilities managers or contractors	LBNL 2015

Table 5. Building prototype, installation, and labor assumptions (smart).

Value	Meaning	Source
100,000	Square feet of lit space	Input
85	Square feet per fixture	LBNL 2015
1,176	Fixtures per building	Calculated
5	Years of Operation	DLC QPL Requirements
$100	Hourly rate for programming by manufacturers and manufacturers' reps	LBNL 2015

3. Results

This section details the study findings of incremental cost for both clever and smart systems. Note that while most products do include configuration tools, they are almost exclusively app-based and free, and thus are not included in the list of costs below.

Incremental Cost of Clever LLLC Systems

As shown in the second section of Table 6 below, the average total incremental cost of clever LLLC systems compared to a system without controls is $49 per fixture, with a range from $35 to $68. As expected, programming is a small fraction (2%) of total fixture cost due to the relatively straightforward programming process. Table 6 below shows the clever system cost components, per-fixture incremental costs, and total and per square foot project costs based on the 40,000 square foot prototype office building. Figure 1 shows the incremental per-fixture cost breakdown.

Table 6. Clever LLLC system cost components, per-fixture costs, and total average project and per square foot costs based on the 40,000 square foot building prototype

	Average	Min	Max
Components Used to Calculate LLLC Per-Fixture Incremental Cost			
LLLC Fixture ($/fixture)	$148	$123	$165
LED Fixture Without Controls ($/fixture)[a]	$100	$88	$110
Programming Cost ($/node)[b]	$1	$0	$2
Gateway ($/gateway)[c]	N/A	N/A	N/A
Server ($/server)[c]	N/A	N/A	N/A
Configuration Tool ($/tool)[d]	$0	$0	$0
LLLC Per-Fixture Incremental Costs			
Incremental Fixture Cost[e]	$48	$35	$66
Programming Cost	$1	$0	$2
Total Incremental Cost	$49	$35	$68
Average Total Clever Project Cost and Per Square Foot Cost – 40,000 Sq. Ft. Building			
Average Total Project Cost[f]	$70,010		
Average Per Sq. Ft. Project Cost	$1.75		

[a] The costs for LED fixtures without controls vary somewhat in Tables 6, 7, and 8 because interviewee responses were averaged for each system type rather than across all responses for all system types.

[b] A node can be a fixture or other element requiring programming such as a switch.

[c] Clever systems do not require gateways and servers because system data is not sent out over the Internet.

[d] Respondents reported that configuration tools are included at no additional charge.

[e] While the average incremental fixture cost can be calculated by subtracting the LED fixture without controls from the LLLC fixture cost, this is not true for the minimum and maximum because these may not be from the same respondents.

[f] The total cost for a clever LLLC project is calculated using the equation below. The values for the equation components are drawn from the information in Tables 4 and 6.

$$= (LLLC\ fixture\ cost\ \times number\ of\ fixtures) + (per\ fixture\ cost\ for\ programming \times number\ of\ fixtures) + cost\ of\ configuration\ tool$$

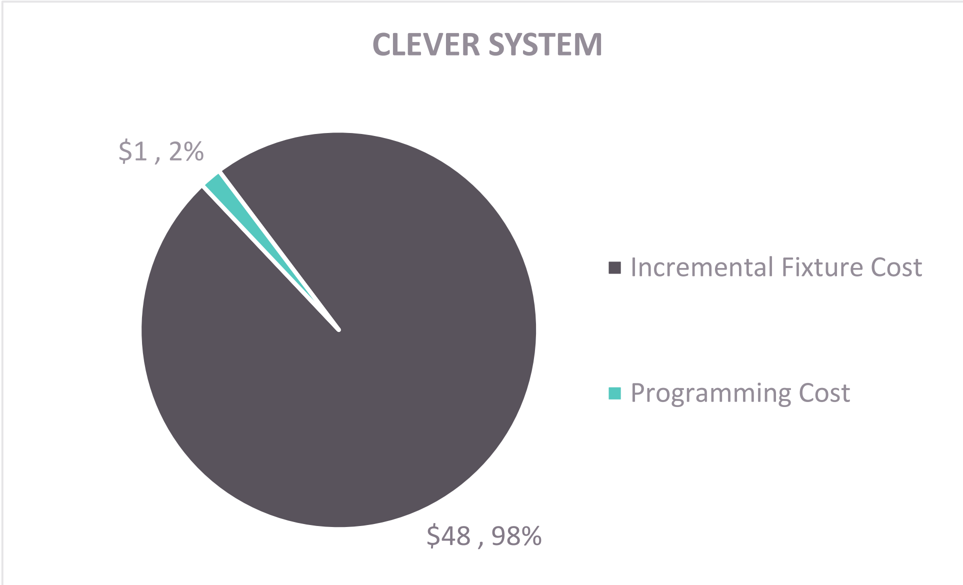

Figure 1. The incremental cost breakdown of clever LLLC systems on a per-fixture basis.

Incremental Cost of Clever-Hybrid LLLC Systems

As shown in the second section of Table 7 below, the average per-fixture total incremental cost of fixtures in clever-hybrid systems is $63, with a range from $37 to $84. Clever-hybrid systems differ from clever systems due to their additional programming, gateway, and server costs.

The clever-hybrid programming cost estimates vary minimally, from $1 to $3 per fixture, with an average cost of $2 per fixture. Programming cost may vary due to variation in configuration tool user-friendliness, contractor familiarity with the system, and typical building complexity.

The average clever-hybrid per gateway cost provided by respondents was $1,200, where the minimum per gateway cost was $350, and the maximum was $3,750. The variation in per gateway cost is loosely dependent on the number of gateways required for the system. This ranged from one to three gateways for a 40,000 square foot building. The projects that required fewer gateways had more expensive per gateway costs.

Table 7 below shows the clever-hybrid system cost components, per-fixture incremental costs, and total and per square foot project costs based on the 40,000 square foot prototype office building. Figure 2 shows the incremental per-fixture cost breakdown.

Table 7. Clever-hybrid LLLC system cost components, per-fixture costs, and total average and per square foot project costs based on the 40,000 square foot building prototype.

	Average	Min	Max
Components Used to Calculate LLLC Per-Fixture Incremental Cost			
LLLC Fixture ($/fixture)	$150	$128	$172
LED Fixture Without Controls ($/fixture)[a]	$93	$55	$130
Programming ($/node)[b]	$2	$1	$3
Gateway ($/gateway)	$1,200	$350	$3,750
Server ($/server)	$500	$500	$500
Configuration Tool ($/tool)[c]	$0	$0	$0
LLLC Per-Fixture Incremental Costs			
Incremental Fixture Cost[d]	$57	$35	$73
Gateway Cost	$3	$1	$8
Server Cost	$1	$1	$1
Programming Cost	$2	$1	$3
Total Incremental Cost	$63	$37	$84
Average Total Clever-Hybrid Project Cost and Per Square Foot Cost – 40,000 Sq. Ft. Building			
Average Total Project Cost[e]	$74,069		
Average Per Sq. Ft. Cost	$1.85		

[a] The costs for LED fixtures without controls vary somewhat in Tables 6, 7, and 8 because interviewee responses were averaged for each system type rather than across all responses for all system types.

[b] A node can be a fixture or other element requiring programming such as a switch.

[c] Respondents reported that configuration tools are included at no additional charge.

[d] While the average incremental fixture cost can be calculated by subtracting the LED fixture without controls from the LLLC fixture cost, this is not true for the minimum and maximum because these may not be from the same respondents.

[e] The total cost for a clever-hybrid LLLC project is calculated using the equation below. The values for the equation components are drawn from Tables 4 and 7 plus an average number of two gateways per building for the 40,000 square foot prototype based on survey responses.

$$= (LLLC\ fixture\ cost\ \times number\ of\ fixtures) + (cost\ of\ gateway \times number\ of\ gateways) + (per\ fixture\ cost\ for\ programming \times number\ of\ fixtures) + cost\ of\ configuration\ tool$$

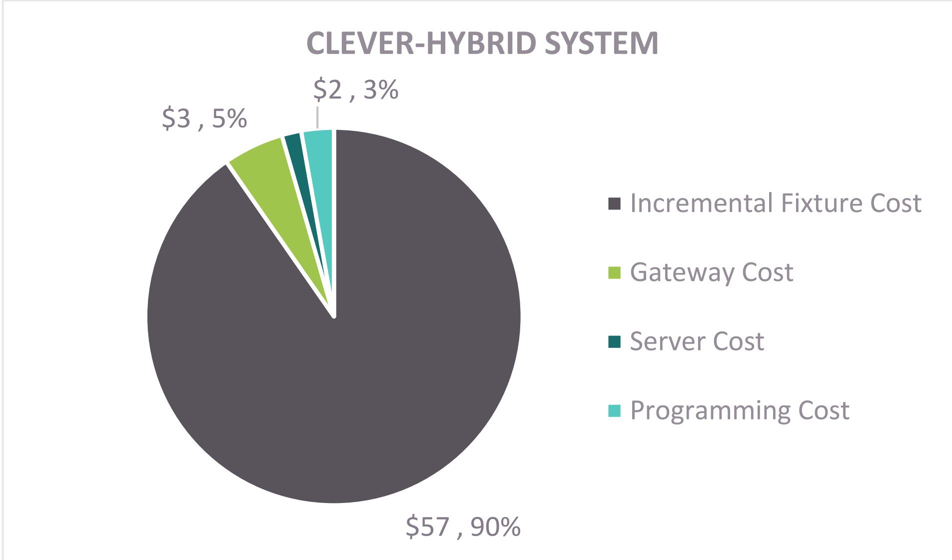

Figure 2. The incremental cost breakdown of clever-hybrid LLLC systems on a per-fixture basis.

Incremental Cost of Smart LLLC Systems

As shown in the second section of Table 8 below, the average per fixture total incremental cost of fixtures in smart systems is $90, with a range from $39 to $166. This wide variation is likely due to the differentiation in services that these various smart systems provide, contractor familiarity and installation volume, and the fact that these are quoted prices rather than an actual project bid.

Due to their increased complexity, smart systems contain additional cost components such as gateway costs, servers or hosting fees, and additional programming that are typically not present in clever systems. As expected, the programming times for smart systems vary widely. The average programming cost is $4 per node. Programming fees for smart systems also vary widely in their cost structure: some programming is performed by a contractor on an hourly rate, while other programming may be performed by a manufacturer’s in-house field team for a much larger fixed price, which includes a guarantee of programming quality and often also includes support services in the cost. The payment structure also varies widely, with some companies including the programming cost as part of their product startup fees.

As shown in the first section of Table 8, smart system gateways cost an average of $718 each but vary significantly from a minimum of $100 to a maximum of $2,000. An average of 19 gateways are required for a 100,000 square foot building, ranging from a minimum of three to a maximum of 34.[11]

Table 8 below shows the smart system cost components, per-fixture incremental cost, and total and per square foot project cost based on a 100,000 square foot building. Figure 3 shows the incremental per-fixture cost breakdown.

[11] One manufacturer representative stated that one hub (gateway) can accommodate 20 fixtures. So, for a 100,000 square foot building, 59 gateways would be needed.

Table 8. Smart LLLC system cost components, per-fixture costs, and total average and per square foot project costs based on the 100,000 square foot building prototype.

	Average	Min	Max
Components Used to Calculate LLLC Per-Fixture Incremental Cost			
LLLC Fixture ($/fixture)	$171	$128	$238
LED Fixture Without Controls ($/fixture)[a]	$93	$93	$93
Programming Cost ($/node)[b]	$4	$2	$5
Gateway Cost ($/gateway)	$718	$100	$2,000
Server Cost ($/server)	$2,130	$1,000	$3,000
Configuration Tool ($/tool)[c]	$0	$0	$0
LLLC Per-Fixture Incremental Costs			
Incremental Fixture Cost[d]	$78	$35	$145
Gateway Cost	$6	$1	$14
Server Cost	$2	$1	$3
Programming Cost	$4	$2	$5
Total Incremental Cost	$90	$39	$166
Average Total Smart Project Cost and Per Square Foot Cost – 100,000 Sq. Ft. Building			
Average Total Project Cost[e]	$220,701		
Average Total Project Cost (Per Sq. Ft.)	$2.21		

[a] The costs for LED fixtures without controls vary somewhat in Tables 6, 7, and 8 because interviewee responses were averaged for each system type rather than across all responses for all system types.
[b] A node can be a fixture or other element requiring programming such as a switch.
[c] Respondents reported that configuration tools are included at no additional charge.
[d] While the average incremental fixture cost can be calculated by subtracting the LED fixture without controls from the LLLC fixture cost, this is not true for the minimum and maximum because these may not be from the same respondents.
[e] The total cost for a smart LLLC project is calculated using the equation below. The values for the equation components are drawn from Tables 4 and 8 plus an average number of 19 gateways per building for the 100,000 square foot prototype based on survey responses.

$$= (LLLC\ fixture\ cost\ \times number\ of\ fixtures) + (cost\ of\ gateway \times number\ of\ gateways) + (per\ fixture\ cost\ for\ programming \times number\ of\ fixtures) + cost\ of\ configuration\ tool$$

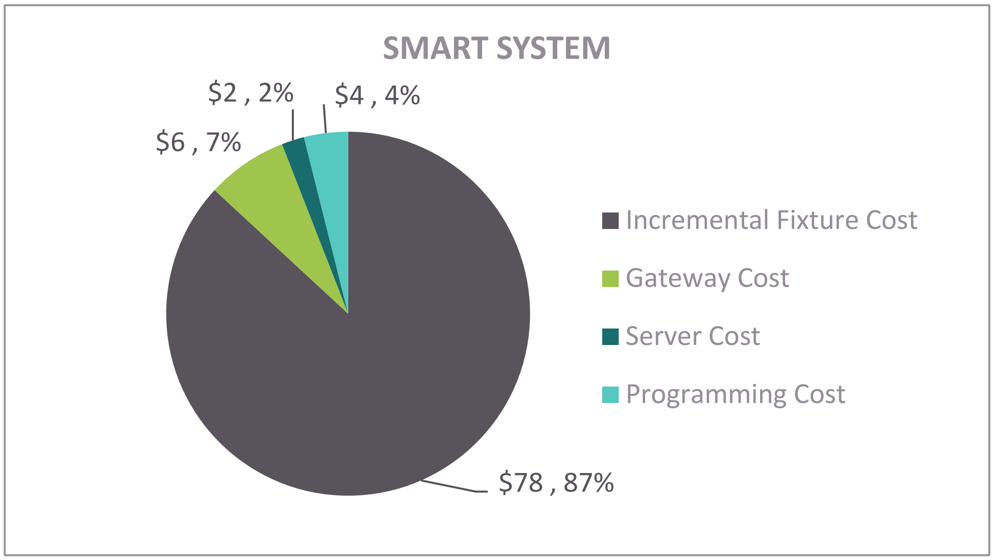

Figure 3. The incremental cost breakdown of smart systems on a per-fixture basis.

Figure 4 below shows the components of the per-fixture incremental costs in clever, clever-hybrid, and smart systems.

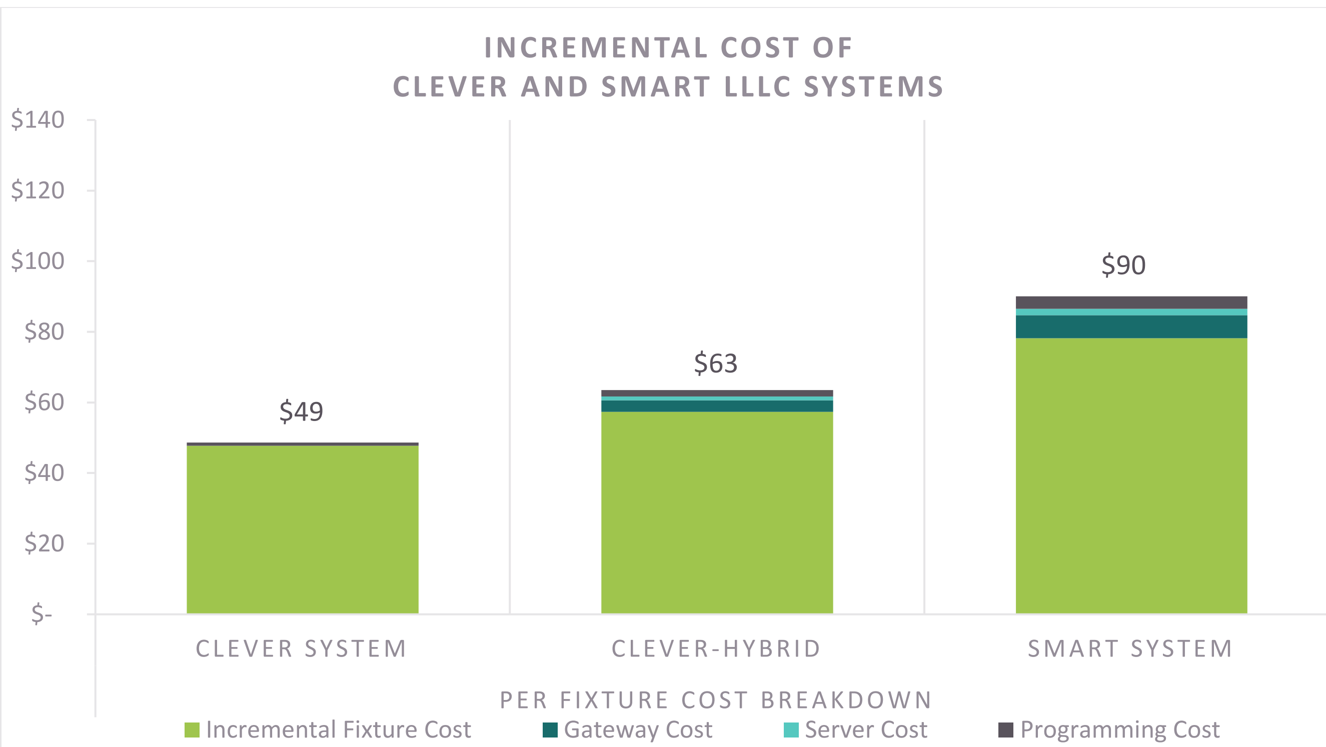

Figure 4. Components of the incremental cost of clever, clever-hybrid, and smart systems on a per fixture basis.

Incremental Cost Between Fixtures Meeting Minimum Code and LLLC Fixtures

In addition to estimating and comparing the incremental cost between an LLLC luminaire and a standard fixture without controls, the research team also analyzed the incremental cost between an LLLC fixture and a fixture with controls that meets minimum code requirements. When comparing the incremental cost of LLLC systems to code minimum, it is important to consider additional costs for a standard system that are not present in LLLC systems. While codes differ across states and project type, codes for offices generally require sensors for occupancy and daylighting, even for projects without networked controls. To approximate the incremental cost between a fixture with controls that meet minimum code requirements and an LLLC fixture, the research team identified components required for a sample code minimum project that would not be included in an LLLC system (controls wiring, standalone sensors, and incremental labor for planning and installation (see Table 9)).

Table 9. Overview of equipment and installation costs found in a sample code minimum and LLLC project.

Cost Type	Cost Component	Code Minimum	LLLC
Equipment	Fixtures	Fixtures	Fixtures w/ integrated sensors
	Controls Wiring	Yes	No
	Switches	Similar for both	Similar for both
	Standalone Sensors/ Relay	Yes	No
	Gateways	No	Yes
	Servers	No	Yes
Installation	Planning / Installation	Controls wiring	Limited/no controls wiring needed

Based on this approach, the research team quantified the costs of 1) controls wiring, 2) standalone sensors, and 3) incremental labor for a code minimum project. A conventional open office (25 fixtures, roughly 2,125 square feet) would generally require wire, two standalone sensors, one powerpack, and one dimmer (roughly $200 for all this equipment).

Wired installation of code minimum controls for an open office requires at least one to two hours of labor (assuming a minimum of $100 per hour), with an additional hour planning the layout of the controls system. This code minimum estimate can vary substantially based on building layout and code requirements.

Table 10. Equipment cost summary for sample code minimum scenario.

System	Code Compliance Additional Cost
Equipment (wiring, standalone sensors, powerpack, dimmer)	$200
Planning and Installation (3 hours at $100/hr)	$300
Code Minimum Cost (total project cost)	$500
Code Compliance Per Fixture Cost (assuming 25 fixtures)	$20

In addition to this calculation, the research team conducted a survey of market actors to estimate the overall rough percentage difference between a lighting project with the minimum required code compliant controls and a lighting project with LLLC. Overall, respondents estimated that a lighting project with LLLC cost an average of 11% more than the cost of a code minimum project, with clever systems being 8% more expensive and smart systems roughly 15% more expensive than a code minimum project. Respondents noted that LLLC equipment was more expensive due to integrated sensors, but LLLC projects typically achieve installation and programming labor savings because of their simplicity and ease of use to achieve code compliance.

Table 11. Percent cost differences between a minimum code compliant lighting project and a lighting project with an LLLC system.

		Percent Cost Difference	
System	**Average**	**Min**	**Max**
Clever	8%	0%	20%
Clever-Hybrid	10%	5%	15%
Smart	15%	10%	20%

To confirm that these responses are generally consistent with each other and in the same ballpark, the research team multiplied a $29 per fixture difference between code minimum and clever LLLC by 25 fixtures to achieve an estimated above code incremental cost of $725.[12]

Assuming a sample code compliant project size of 2,125 square feet and an estimated project cost of $2 per square foot for a total of $4,250, the research team multiplied this by the average incremental percentages given by market actors (0% and 20%) to achieve an estimated incremental cost range of $0 to $850. The $725 estimate falls within these bounds, and thus is a good first order estimate. In future work, the research team recommends developing a more refined approach if this code minimum number is critical to NEEA's program efforts. Figure 5 below shows the components of the incremental cost of clever, clever-hybrid, and smart systems above code minimum on a per-fixture basis.

[12] The estimated average incremental $49 per fixture cost of a clever system found in Table 6 minus the code minimum cost per fixture found in Table 10.

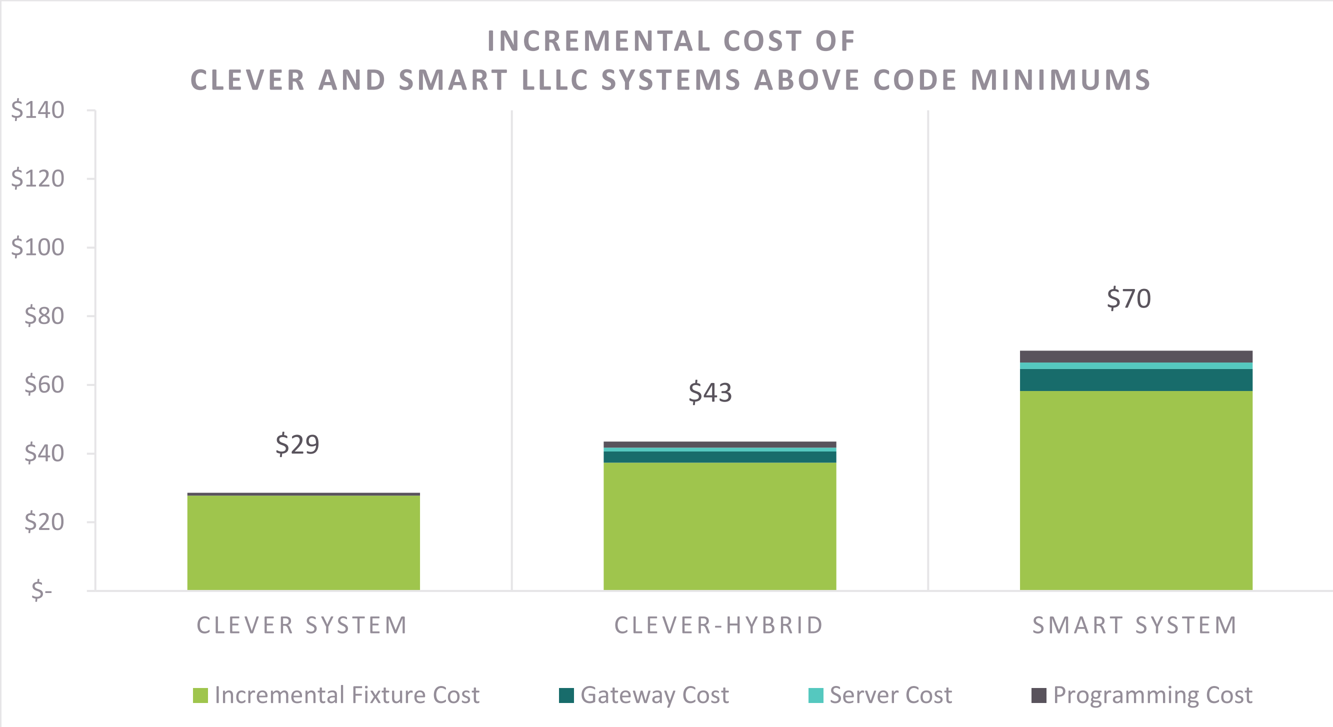

Figure 5. Components of the incremental cost of clever, clever-hybrid, and smart systems above code minimum, on a per fixture basis. This assumes an average of $20 per fixture cost above code minimum.

4. Comparison to Previous Study Years' Results

To track the changes in LLLC system costs over time, the results of this study were compared to those from previous studies conducted in 2017, 2018, and 2019. Each study focused on characterizing the programming, one-time costs, ongoing costs, gateway and incremental fixture costs for all three categories, clever, clever-hybrid, and smart systems. In total over these four years, the research team has collected a combined 83 price estimates (21 clever, 24 clever-hybrid, and 38 smart systems) from 44 individual interviewees (27 manufacturers, 10 manufacturer representatives, one distributor, and six contractors). Table 12 indicates the year over year changes from 2017 to 2020.[13]

Since 2017, the more basic clever systems have seen a 28% decrease in incremental per fixture costs, with some annual variability due to changes in feature sets and components. This generally decreasing trend may be due to increasing competition and economies of scale. The average price for more complex, smart systems has oscillated but shows an overall decrease in costs over time. This oscillation may be due to the continued addition of incremental feature packages and capabilities that the smart systems can enable. Smart systems remain more expensive than their clever-hybrid counterparts, and their value proposition is likely focused on increasing value from non-energy benefits. Smart systems continue to be more expensive and have more complex pricing systems than clever systems, with some installation costs often wrapped into ongoing subscriptions.

[13] In 2017, clever and clever-hybrid systems were a single system category.

Since 2018, clever-hybrid systems have seen a 21% decrease in incremental per fixture cost over time. This smaller decrease is likely due to the higher price point and greater number of product feature sets that create consumer value.

Table 12. Incremental per-fixture cost between 2017 and 2020, as well as percent change between 2017 to 2020.

	Incremental Cost (per fixture)				
Year	**2017**	**2018**	**2019**	**2020**	**Percent Change 2017-2020**
System	Average	Average	Average	Average	Average
Clever	$68	$51	$59	$49	-28%
Clever-Hybrid	N/A	$80	$63	$63	-21%
Smart	$107	$156	$113	$90	-16%

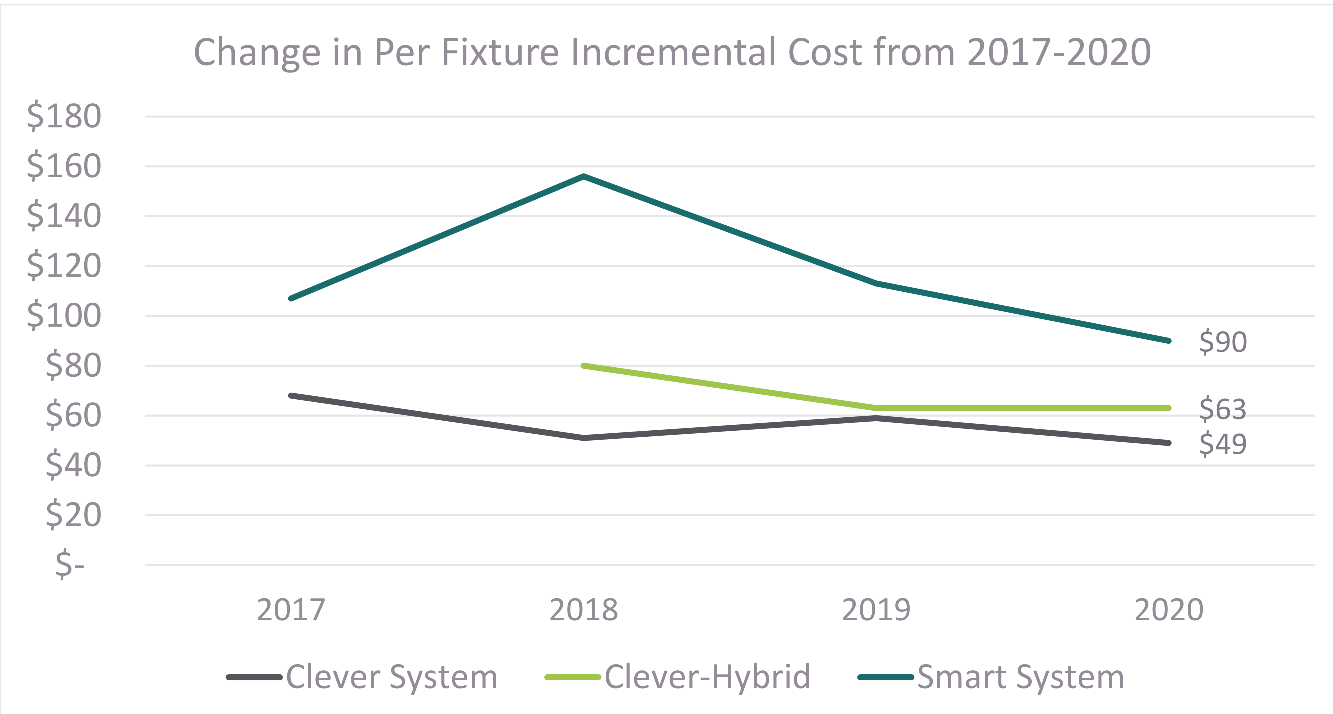

Figure 6. Changes in per fixture incremental costs for clever, clever-hybrid, and smart systems between 2017 to 2020.

Attributing the Higher Incremental Cost of Smart Systems

The majority of respondents for smart systems indicated that the higher incremental cost of a smart system compared to a clever or clever-hybrid system was primarily due to the increased IoT connectivity and the supplemental, non-energy features. While the motivation and cost for developing a much more robust system are driven primarily by controllability, monitoring, and other non-energy features, smart systems do provide an improved ease of controllability through a computer or interface. For example, all smart systems have a scheduling feature, while not all clever-hybrid systems do.

Most clever-hybrid systems offer some mechanism of monitoring but lack the major non-energy benefits of smart systems. While it is difficult to determine the additional energy savings that smart systems achieve over clever-hybrid systems (there is not good data on this topic at present), there is consensus that the incremental step to smart systems is driven primarily by non-energy features. 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 portion of these IoT systems. An alternate approach could be attributing a fraction (10-25%) of the price difference between clever-hybrid and smart systems to account for supplemental features that increase energy savings.

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 as a way to standardize costs for a code minimum compliant project, for a clever, clever-hybrid, and smart system, and an NLC project.
- Further assess the functional differences (from a consumer perspective) between clever, clever-hybrid, and smart LLLC systems.
- Consider identifying whether it is appropriate to increase the sample size of this study in order to improve certainty.