UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Investigation of the Potential for DDC Lighting Control Retrofits at UBC – A Technical Viability and Economic Analysis

Andrea Luk

University of British Columbia

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Final Project Report

Investigation of the Potential for DDC Lighting Control Retrofits at UBC – A Technical Viability and Economic Analysis

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Prepared by Andrea Jane Luk

ECE Technical Supervisor: Dr. André Ivanov
Direct Supervisor: Dr. Paul Lusina

1. ABSTRACT

This research paper investigates feasibility of implementing Direct Digital Controls in lighting systems of existing UBC buildings as a means to reduce energy consumption and Greenhouse Gas emissions. Through in person, phone interviews, email correspondence and online research, information was gathered to evaluate the suitability of five specific DDC lighting controls solutions.

Two companies were found to be ideal candidates and a break even feasibility analysis was performed for one of the companies. The financial analysis identified strategies to reduce electricity consumption and laboratories as a good candidate for energy savings. It appears that DDC controls are worth further investigation and given the lack of retrofit costs provided, more information should be gathered as explained in this report.

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4. GLOSSARY

Apparent Power	Vector sum of real power and reactive power.
BACnet	An ANSI, ASHRAE, and ISO standard data communications protocol for building automation and control networks. It specifies six levels of device capabilities (Class 1 to Class 6).
Carbon Offsets	A financial penalty paid to a third-party company in compensation to reduce greenhouse gas emissions.
Direct Digital Controls	Automated control of an environment that is programmable by logic, usually microprocessor.
Greenhouse Gas Emissions	Atmospheric gases such as CO_2 that contribute to global warming of the Earth.
Harmonics	Voltages or currents with integer multiples of the fundamental power frequency, typically 60Hz.
Net Present Value	The measurement of the net value of a project in today's dollar terms, by taking into account the time value of money.
Payback Period	A financial metric that estimates the length of time it takes for the profit to equal the initial outlay for the investment.
Power Factor	A ratio of Real Power to Apparent Power between 0 and 1 that rates the efficiency of power delivered.
Power Quality	The combination of the quality of voltage and current waveforms.
Reactive Power	Created by inductance and capacitance elements but is stored and does not contribute to useful work.
Real Power	Useful power that can produce work.

5. LIST OF ABBREVIATIONS

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BACnet	Building Automation and Control Network
DALI	Digital Addressable Lighting Interface
DDC	Direct Digital Controls
GHGe	Greenhouse Gas Emissions
LEED	Leadership in Energy and Environmental Design
NPV	Net Present Value
ROI	Return on Investment
TCP/IP	Transmission Control Protocol/Internet Protocol
UDP/IP	User Datagram Protocol/Internet Protocol

6. INTRODUCTION

This project investigates the feasibility of installing Direct Digital Controls (DDC) for lighting systems of existing UBC buildings. The analysis is based on the cost savings on building operation (reduced energy consumption), and Carbon Offset expense (through reduced Greenhouse Gas emissions (GHGe)).

The primary objective is to create a methodical template to compare and evaluate five vendors selected by the UBC Sustainability office, which can be re-used in future evaluations. The secondary objective is to then shortlist a few lighting companies to investigate further. The third objective is to determine the most appropriate room types, (e.g. classrooms, labs, offices, etc.) and configurations for retrofitting lighting control, through a Cost-Benefit Analysis.

Lighting accounts for up to 30% of energy consumption in buildings. Implementing DDC lighting control at UBC could provide substantial energy and cost savings, reduce GHG emissions and help UBC meet its GHG reduction targets. Additionally, these energy savings could delay or eliminate the need for a new transmission line which would require a large capital investment. Finally, DDC lighting control can enhance students' learning environments and increase occupant satisfaction

This is a new project launched by the UBC Sustainability and SEEDS initiative. The only related work performed was in January 2013, where a Comparative Lighting Analysis for the Forest Science Centre was performed by Derek Knight of E.B. Horsman & Son. The report showed that it was not feasible to install controls from Fifth Light as it took 37 years for payback.[1]

Since this project is a brand new initiative, the scope was defined and narrowed with the ECE and Sustainability department at UBC. Requirements were gathered based on important criteria to UBC. Five vendors were contacted and rapport was developed with appropriate contact persons. The vendors were analyzed and evaluated using a rubric, then ranked objectively based on evaluation criteria that were weighted according to importance. A financial analysis was performed to determine whether or not there is a business case for the shortlisted companies in question. The impact of GHGe reduction was calculated and also equated to a cost savings associated with the reduction in Carbon Offset expenses. Through the analysis, appropriate space types at UBC for retrofitting lighting controls were identified, and sensitive factors that increase retrofit costs were also determined. Finally, key technical aspects were investigated, including the impacts and importance of power factor, and the DDC network layout, reliability, security, and traffic.

The primary constraints of this project were limited information availability and time to collect information from the five companies.
Not included in the scope is the comparison of whether other buildings are similar to MacLeod enough for consumptions savings projection across the entire UBC campus. Due to time constraints, further analysis of cost savings of light/sensor replacement from reduced burn hours was excluded. Also the comparison of products from vendors against their datasheets and claims, such as power factor can be experimented in the laboratory.

This report is divided into the following primary sections: Equipment and Methodology, Designs and Experiments, and Results.

7. BODY

7.1 Equipment and Methodology

7.1.1 Evaluating Companies Method

A template to rationalize the scoring and evaluation of the five lighting control companies was developed and improved through multiple iterations.

In the first method, the prioritization table calculated a score for each company by adding weighted scores in each criterion important to UBC. This was a simple and quick first triage method. The importance and weighting can be changed and the template can be re-used in the future. However without objectively defining each score and the categories ‘Excellent’ to ‘Does Not Meet Requirements’, this method is not auditable and could result in different results depending on the evaluator’s personal judgment.

First Method

Scoring Scale	
5	Excellent
4	Above Average
3	Average
2	Below Average
1	Does not meet requirements
0	Information not available

A second method was devised to create a company-scoring matrix. It used a weighted sum of the ratings to determine vendor ranking. The separate points for each criterion show the breakdown of a company’s total score. This method is more objective than the first method because a rubric model explained in detail how a category was ranked from 0 to 5. (A rubric is a scoring tool used to evaluate a list of criteria.)

This matrix can be used by Sustainability in future comparisons with other companies. Note that importance weights can be changed.

Second Method – Importance Weights

UBC Importance Scale	
5	Critically Important
4	Very Important
3	Important
2	Moderately Important
1	Of Little Importance
0	Not important

Second Method – Rubric Table

	Excellent **5**	**Above average** **4**	**Average** **3**	**Below average** **2**	**Poor** **1**	**Information not available** **0**
Background and Experience						
Energy Savings						
Compatibility						
Power Factor						
Installation Costs						
Maintenance Costs						

7.1.2 Business Analysis Method

Installation costs were not provided by vendors because they would need to a study and analyze energy consumption of a building before providing a quote, so the financial analysis was developed to assume a breakeven point and positive Net Present Value (NPV) after five years. For an overview of NPV please see Appendix on page 5. Similarly, other assumptions are used in the analysis where information is unknown, and are clearly documented.

The calculations were based on the MacLeod Building size and layout, and the rooms were categorized as classrooms, offices, study spaces, laboratories, or hallways. A DDC system can reduce lighting energy consumption using a number of different strategies. Given time constraints and limited information, the business model developed accounts for cost savings incurred by employing two primary strategies. The first strategy is to substitute artificial light with daylight by turning off banks of lights near windows during daylight hours. The second strategy is to schedule lights to turn off after core operating hours.

7.1.3 Technical Analysis Method

Based on the technical details that were provided by some vendors, a technical evaluation of network architectures was performed. In other aspects where little information was provided by vendors, a discussion of further technical considerations is presented for future consideration. Those other aspects include Power Quality, as well as Communications Protocols.

7.2 Designs and Experiments:

Due to the nature of this project, all designs and experiments are related to the analysis of the five DDC vendors. Prior to analyzing the companies, data was gathered and evaluation tools were developed.

Data gathering methods included:

- In-person interviews [2], [3]
- Email correspondence [2], [4]
- Phone interviews [4]
- Online research [5]--[10]

As mentioned in the Equipment and Methodology section, the second method for evaluating companies involved a rubric with clear definitions for scoring across different categories.

Rubric Model for Scoring Matrix

A 0 is assigned to any criterion that does not meet requirements.

	Excellent **5**	**Above average** **4**	**Average** **3**	**Below average** **2**	**Poor** **1**
Background and Experience	Credible and highly reputable Established by experienced founders.	Case studies/White Papers available. Good testimonies from multiple clients.	Has retrofitted schools. Few examples on website.	Minimal experience in retrofitting lighting systems for universities/colleges.	Website does not appear to be credible. Contact information is not available.
Energy Savings	Specific data provided, proven results from completed projects.	Critical issues and key problems supported by effective solution.	Key points clearly identified for energy savings. Cases occasionally referenced.	Little evidence for energy savings provided.	Incomplete research and documentation on claims.
Compatibility	Class 2 BACnet IP compatible. 2-way read/write communication. Compatible with some other protocols. I.e. Modbus, LonWorks, Metasys N2, NiagaraAX	---	Class 2 BACnet IP compatible. 2-way read/write communication.	Class 1 BACnet IP compatible. Read-only communication.	Proprietary. Not compatible with Douglas Controls; WNG-2133 Gateway.
Power Factor	No PF distortion	$0.97<PF\leq0.99$	$0.95<PF\leq0.97$	$0.90\leq PF\leq0.95$	$PF\leq0.90$
Installation Costs	Effective installation plan to reduce costs, i.e. pilot program,	No fixed network topology, hybrid	Number of devices minimized, wiring minimized (e.g. communications via power wires)	Minimum network layout customization allowed.	Fixed network topology, no allowance for customization.
Maintenance Costs	Effective and robust solution that requires minimal maintenance. Easy network modifications. Thorough variety of monitoring and feedback, can display building's real-time statuses on dashboard, plus extra features e.g. security alert, flags set at luminaire end-of-life, etc.	Effective and robust solution that requires minimal maintenance, i.e. various remote adjustments, data logging, status monitoring and generating reports on demand.	Software program capable of monitoring and flagging statuses.	Data logging feature available. Simple remote adjustments.	No data logging feature. Not a very capable software program.

7.2.1 Technical Analysis

Network Architecture

Encelium:
Encelium's GreenBus II network topology typically propagates in a daisy chain fashion from device to device, it is essentially topology free so 'T' connections are acceptable as mentioned by Weigand [2].

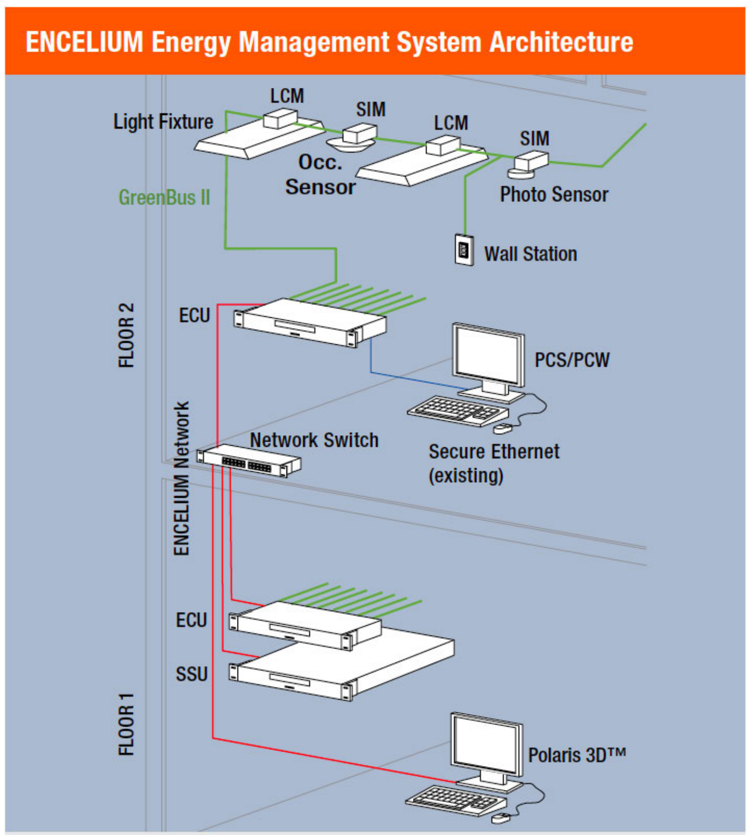

Figure 1. Illustration of Encelium's Network Architecture [6]

Pros: Less wiring overall compared to bus system network, simple installation.

Cons: A whole section of sensors and lights can be affected if there is a sensor malfunction or short circuit, as all devices connected downstream are affected. Every upstream node must actively pass communication back and forth, which could have negative traffic and energy consumption impacts. Also, future modifications and maintenance may require a disruption to the entire lighting system if the network topology is changed or additional luminaires are added in the middle of the daisy chain.

Summary: Cheaper installation costs than bus system network but less robust solution considering maintenance and future modifications, as well as potential traffic and energy concerns.

Crestron:

Crestron offers multiple network wiring configurations that include centralized (i.e. bus system), distributed (i.e. daisy chained), and a hybrid of the two, depending on lighting layouts and different uses of rooms [4], [7].

Centralized Architecture:

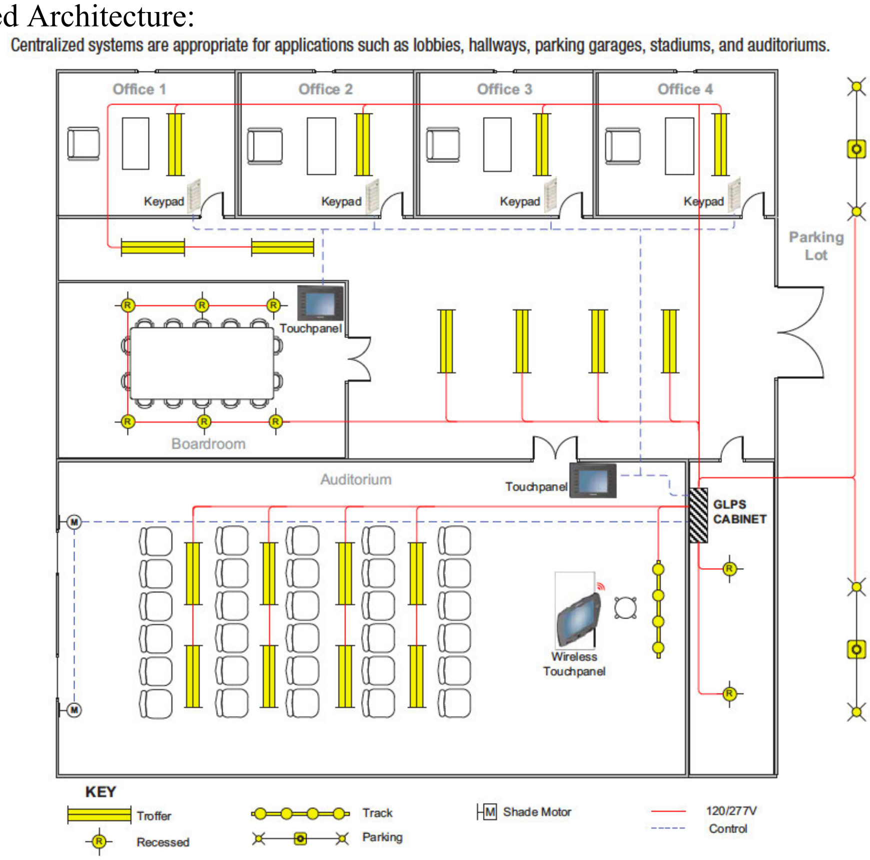

Figure 2. Illustration of Crestron's Centralized Architecture [7]

Distributed Architecture:

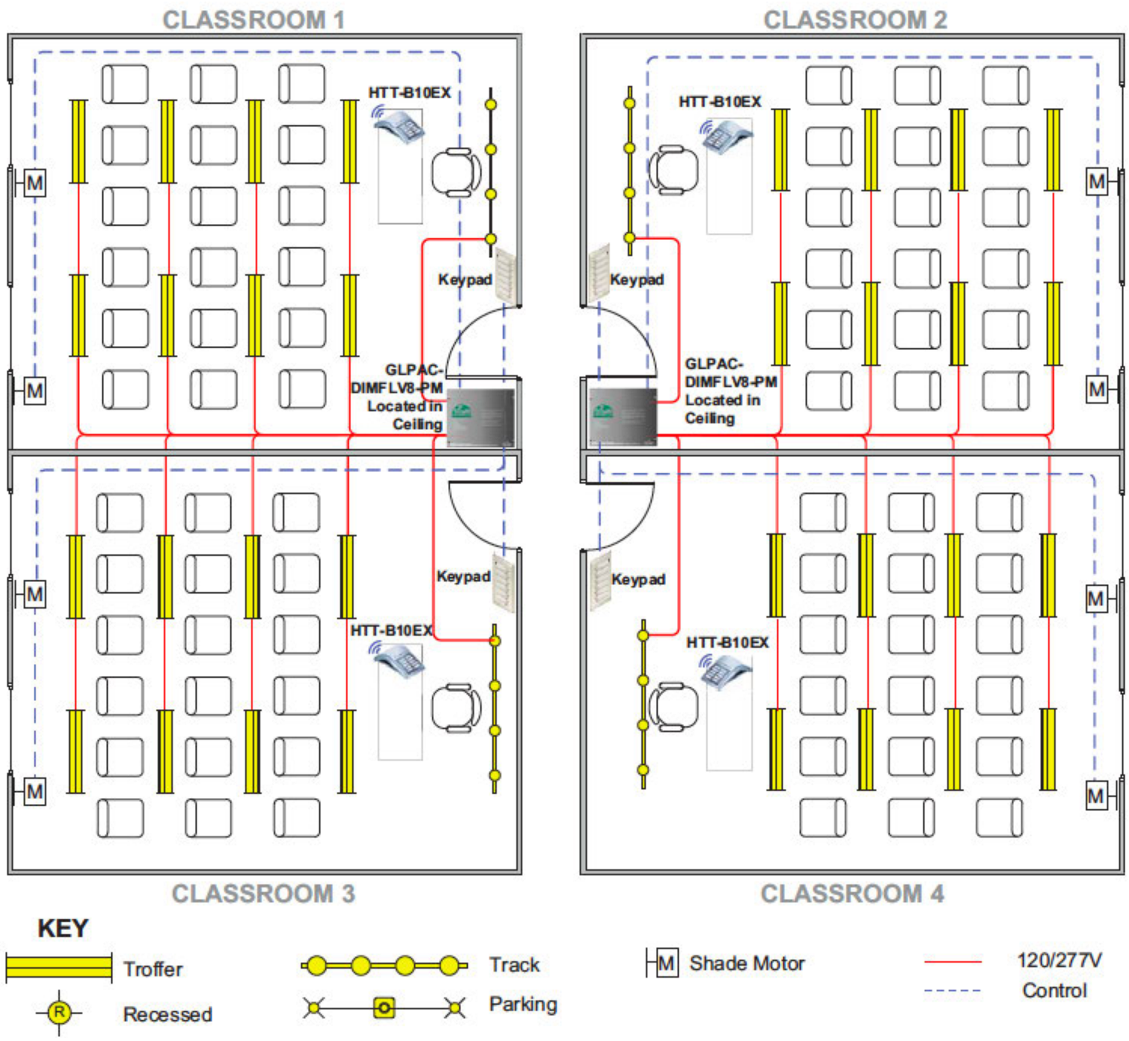

Figure 3. Illustration of Crestron's Distributed Architecture [7]

Hybrid Architecture:

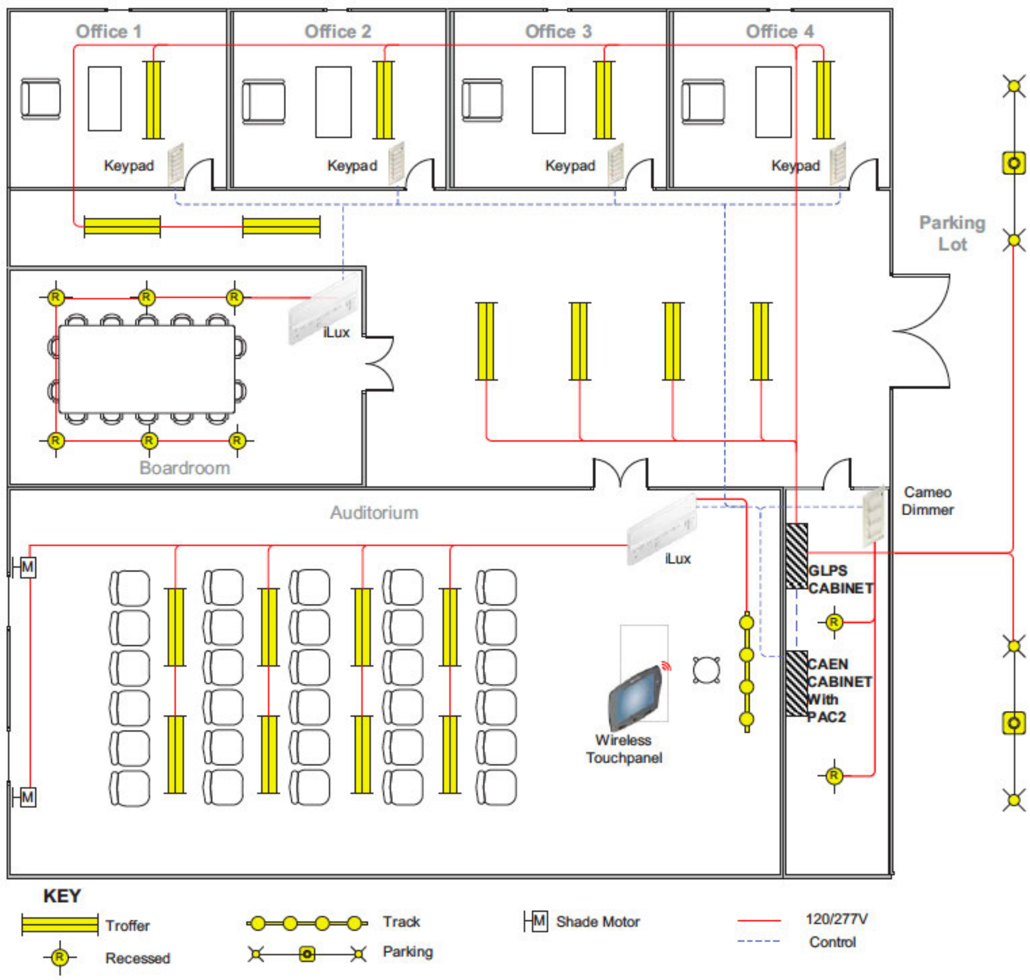

Figure 4. Illustration of Crestron's Hybrid Architecture [7]

<u>Summary</u>: Crestron offers full flexibility by supporting multiple network architectures. This is ideal for a DDC solution, though will require further investigation to understand cost and management implications of each architecture.

Power Quality: Power Factor and Harmonics

Power quality is affected by power factor and harmonics. [12] High power quality is also very important to UBC as decreased power quality results in increased energy demand consumption. As seen below, the demand rate (in kVA) is 170% greater than the regular energy rate. The Energy Demand rate depends on the Apparent Power required by the system.

Energy Rates $/kWh	$0.03814	$/kWh
Energy Demand $/kVA, monthly	$6.507	$/kVA, monthly

Power Factor is essentially a ratio of Real Power to Apparent Power. A ratio of Real Power to Apparent Power between 0 and 1 that rates the efficiency of power delivered. Apparent Power is the vector sum of Real Power (in kW) and Reactive Power (in kVARs). Real Power is useful power that can produce work, while Reactive Power, is created by inductance and capacitance elements but is stored and does not contribute to useful work. Therefore to maintain high power quality, Reactive Power must be reduced as much as possible. [12]

The effects of harmonics in the electrical network also increase current consumption and can cause thermal or hardware damage to other electrical equipment on the network and communication errors due to voltage drop. Harmonics are deviations from the fundamental waveform where voltages or currents are integer multiples of the fundamental power frequency, typically 60Hz. The distortions of the normal electrical current waveform and are commonly generated by devices such as AC to DC rectifiers, which are nonlinear loads. In the case of a rectifier, the diodes inside are nonlinear devices because the current and voltage do not have a linear operating characteristic. Upon operation the rectifiers will distort power by shifting the voltage or current phase angles.

Since inductive, capacitive and nonlinear elements affect power quality, it is therefore important to examine the elements in devices provided or endorsed by each company.

Encelium claims to have no distortion at all and Crestron indicate that their equipment operates at a power factor of 0.99 [2], [4].

Communication Protocols:

BACnet is the primary communication standard used in DDC systems [5]. Below is additional information:

- BACnet standard from ASHRAE, ANSI, ISO
- UBC requires Class 2 for read and write
- Uses standard User Datagram Protocol/Internet Protocol, (UDP/IP) to send and receive packet information.

UDP/IP sends simple and lightweight packets of information in an unordered fashion, but has no traffic congestion control. The downside is that it is not 100% reliable because there is no confirmation between the 2 communicating devices. UDP/IP does not cushion its packet information with packet order to be expected on the receiving end or error check bit. Although it is not 100% reliable, using UDP/IP makes more sense than using other protocols such as TCP/IP since data transmission is not time-sensitive.

7.2.2 Business Case Analysis

UBC's primary objective is to reduce GHGe, and UBC makes investments that will break even within five years. To reduce GHGe, it would be desirable to proceed whether or not a profit will be made from installing DDCs, as long as the system breaks even [13].

This information was used to calculate financial savings due to reduction of Carbon Offset payments, energy savings through reduced consumption, and actual amount of GHGe reduction (tonnes CO_2).

	UBC Costs		
Operational Costs	Energy Rates $/kWh	$0.03814	$/kWh
	Energy Demand $/kVA, monthly	$6.507	$/kVA, monthly
	Applicable Taxes (7.40% for PST & ICE fund levy + 1.65% for GST)	9.05%	
	Rate Rider	5.20%	
	Emission Factor	25	tCO2e/GWh
	Offset Costs	$25	$/tCO2e
	Offset Costs equivalent	$625	$/GWh
Maintenance Cost	Labour costs - relamping requires 2 ppl at $40/h	$80	$/h

Source: Provided by UBC Sustainability [13]

Variables used for calculations such as inflation rate were retrieved through an interview with a Financial Planning Advisor at a TD Canada Trust, a major bank across Canada [3].

Assumptions were made to simplify calculations and also because not all information was made available. All fixture types are assumed to be fluorescent lamp of type T8, rated at 32 Watts [14] based on UBC Interior Lighting Technical Guidelines [15].
The number of lights associated with each category of room type were taken on average and extrapolated for the entire building. Lights in all accessible rooms were accounted for, however some restricted rooms and the 5th floor could only be estimated. Therefore the total number of lights in a building is only an approximation.

Refer to tables that follow, which provide detail for above summary:

Assumptions

MacLeod Building	Building	Classroom	Study Space	Lab	Office	Hallway	Comments, Assumptions
average rated Watt/light	-	32	32	32	32	32	*assume all fixtures are T8s rated at 32W
approx. # lights per room, hallway	-	43	16	84	16	60	
approx. # rooms in building	84	6	46	21	6	5	
approx. # lights	3,154	258	736	1764	96	300	
approx. square footage per room	-	1,000	100	1,000	300	2,000	
approx. square footage	43,400	6,000	4,600	21,000	1,800	10,000	

Strategy 1 analyzes the potential energy savings achieved by turning off lights that are nearby windows, during daylight hours. The scenario, below, estimates how many lights are near windows for each of the different space types (e.g. classroom, study space, etc.), using the MacLeod Building as a model. From this, the total energy savings can be calculated across all the candidate lights and space types. Also, the corresponding GHGe and their Carbon Offset equivalent value can be added into the total annual savings.

Strategy 1: Turn off lights near window	**Building Savings**	**Classroom**	**Study Space**	**Lab**	**Office**	**Hallway**	*Units*	**Comments, Equations**
average # lights by window	-	14	4	28	8	10	-	
average daylight hours	-	12	12	12	12	12	*h/day*	(daylight hours June 21 + daylight hours Dec 21) /2
Savings energy/day per room	-	5376	1536	10752	3072	3840	*Wh/day/rm*	(#lights unused/rm) x (W/light) x (hours unused/day)
energy cost $/kWh	-	$0.03814	$0.03814	$0.03814	$0.03814	$0.03814	*$/kWh*	
Savings $/day per room	-	$0.21	$0.06	$0.41	$0.12	$0.15	*$/day/rm*	(Wh/day/rm) x (k/1000) x $/kWh
Savings $/day in building	-	$1.23	$2.69	$8.61	$0.70	$0.73	*$/day*	($/day/rm) x #rm
Savings energy/year	133713	11773.440	25789.440	82414.080	6727.680	7008.000	*kWh/year*	(Wh/day/rm) x (365d/yr) x #rm x (k/1000)
Savings $/year	$5,100	$449.04	$983.61	$3,143.27	$256.59	$267.29	*$/year*	*assume lighting system runs every day of the year
tCO2e/GWh	-	25	25	25	25	25	*tCO2e/GWh*	
Savings tCO2e/year	3.34282	0.294336	0.644736	2.060352	0.168192	0.1752	*tCO2e/year*	(kWh/year) x (tCO2e/GWh) x (G/1,000,000k)
$/tCO2e	-	$25.00	$25.00	$25.00	$25.00	$25.00	*$/tCO2e*	
Savings $/year in Carbon Offsets	$84	$7.36	$16.12	$51.51	$4.20	$4.38	*$/year*	(tCO2e/year) x ($/tCO2e)
Total Savings $/year including offset equivalent	$5,184							

Strategy 2 estimates the cost savings from turning off lights during non-regular working hours and compares the costs savings against a building that does not turn off lights on a schedule. Similar to in Strategy 1, the analysis below estimates the cost savings and GHGe Carbon Offset equivalent savings for all for all of the different space types.

Strategy 2: Schedule lights to turn off after hours	**Building Savings**	**Large Classroom**	**Study Space**	**Lab**	**Office**	**Hallway**	*Units*	Comments, Equations
average work hours	-	13	13	13	13	13	*h/day*	*assume work hours are from 6am to 7pm
hours unused	-	11	11	11	11	11	*h/day*	24h/day - 13h of work/day
Savings energy/day per room	-	15136.000	5632.000	29568.000	5632.000	21120.000	*Wh/day/rm*	(W/light) x (lights/rm) x (hours unused/day)
energy cost $/kWh	-	$0.03814	$0.03814	$0.03814	$0.03814	$0.03814	*$/kWh*	
Savings $/day per room	-	$0.58	$0.21	$1.13	$0.21	$0.81	*$/day/rm*	(Wh/day/rm) x (k/1000) x ($/kWh)
Savings $ /day in building	-	$3.46	$9.88	$23.68	$1.29	$4.03	*$/day*	($/day/rm) x #rm
Savings energy/year	405225.92	33147.840	94561.280	226638.720	12334.080	38544.000	*kWh/year*	(Wh/day/rm) x (365d/yr) x #rm x (k/1000)
Savings $/year	$15,455.32	$1,264.26	$3,606.57	$8,644.00	$470.42	$1,470.07	*$/year*	*assume lighting system runs every day of the year
tCO2e/GWh	-	25	25	25	25	25	*tCO2e/GWh*	
Savings tCO2e/year	10.130648	0.828696	2.364032	5.665968	0.308352	0.9636	*tCO2e/year*	(kWh/year) x (tCO2e/GWh) x (G/1,000,000k)
$/tCO2e	-	$25.00	$25.00	$25.00	$25.00	$25.00	*$/tCO2e*	
Savings $/year in Carbon Offsets	$253.27	$20.72	$59.10	$141.65	$7.71	$24.09	*$/year*	(tCO2e/year) x ($/tCO2e)
Total Savings $/year including offset equivalent	$15,708.58							

As mentioned in the Equipment and Methodology section, the five DDC vendors were unable to provide quotes for equipment and installation costs. In fact, only Encelium was able to provide detailed information on the equipment required for their solution. Therefore, cost assumptions are made to show the maximum total equipment and installation costs that would still be feasible for installation.

	Cost Assumptions for Break Even Scenario		Units	Comments, Equations
Encelium Equipment	Luminaire Control Module:	$25	$	*assumed 1 for every 4 lights
	Photo Sensor:	$30	$	*assumed 1 per room
	Accessory Control Module:	$30	$	*assumed 1 per floor
	Energy Control Unit:	$100	$	*assumed 1 per floor
	DALI Bridge:	$30	$	*assumed 1 per floor
	System Support Unit (database server) :	$900	$	*assumed 1 per bldg
	Miscellaneous:	$1,470	$	*assumed
	Estimated Equipment Cost:	$25,402.50	$	
Initial Installation Labour Cost	lightbulbs/h:	5	#light/h	
	total hours of installation per bldg:	631	h/bldg	(#lights/bld)g x (h/light)
	labour cost:	80	$/h	
	total labour cost per bldg:	$50,464.00		(h/bldg) x ($/h)
	Estimated Installation Cost:			
UBC Maintenance Cost	lightbulbs/h:	5	#light/h	*'light' can also include other devices in system architecture, such as sensors
	total hours of maintenance per bldg:	63.08	h/bldg	(#lights/bld)g x (h/light)
	labour cost:	80	$/h	*relamping requires 2 people at $40/h [#]
	Estimated Maintenance Cost:	$5,046.40		(h/bldg) x ($/h)
	Sample Building:	MacLeod		
	Total # floors:	5		
	Interest rate:	4.00%		
	Inflation rate:	2.30%		

7.3 Results:

Below is the evaluation of the five DDC vendors selected by the UBC Sustainability Office, scored according to the rubric included in the Design and Experiments section. Due to the limited information provided by some of the vendors, scores differed greatly and Encelium and Crestron are the recommended companies to further investigate.

Encelium was able to provide detailed White Papers (case studies) [6] that clearly showed the benefits of their system and how it could work in a university setting. Also, the luminaire control modules from Encelium are only capable of DC switching, which does not lower the quality of the power system.

On the other hand, Crestron has more project history available to demonstrate their background and experience. Also, their network topology is more flexible, and supports centralized, distributed and hybrid architectures [7]. This gives Crestron an advantage for installation as buildings are each different and may require different topologies. Finally, the Crestron system is also potentially more robust because it is not restricted only to a distributed architecture where an issue can affect many devices connected downstream.

		Vendors				
Evaluation Criteria	*Weight*	Fifth Light	Encelium	Crestron	nLight	Lutron
Background and Experience	2	4	3	5	0	0
Energy Savings	5	0	5	3	0	0
Compatibility	5	1	4	4	3	3
Power Factor	5	3	5	4	0	0
Installation Costs	3	0	3	4	0	0
Maintenance Costs	5	0	3	5	0	0
	Total Score	28	100	102	15	15
	Decision:	Investigate Encelium and Crestron				

The table, below, summarizes the results from the two strategies, and cost assumptions discussed previously in the Designs and Experiments section. Those annualized costs and savings are used to calculate NPV of the five-year period, which is consistent with the investment guidelines provided by UBC Sustainability.

Through all of these financial analyses, one important result is that the overall business case appears to be very sensitive to the cost of each Luminaire Control Module, because the number of control modules is proportional to the number of luminaires in a building. Since there are thousands of luminaires per building, this installation cost adds up very quickly. Further, it shows that strategies to group a bank of lights, known as "zoning," can also greatly reduce retrofit costs.

It should be noted, below that the GHGe Offset Credit values have already been taken into account in the annual cost savings, so the CO_2 reduction of 10 tonnes per year has already been considered as part of the benefits.

		Year 1	Year 2	Year 3	Year 4	Year 5
	Energy Savings					
	Strategy 1	$5,183.37	-	-	-	-
	Strategy 2	$15,708.58	-	-	-	-
	Total Saving Cash Flow	$20,891.95	$21,372.47	$21,864.03	$22,366.91	$22,881.35
	5-year NPV of Savings	$97,211.64	This is the total benefit over 5 years, adjusted into present value at Year 1 dollars to account for the time-value of money.			
	Costs					
Encelium	Cost of Retrofit + Equipment	$25,402.50	-	-	-	-
Encelium	Installation Labour Cost	$50,464.00	-	-	-	-

UBC Maintenance Cost	$5,046.40	$5,248.26	$5,458.19	$5,676.51	$5,903.57
Total Costs Cash Flow	$80,912.90	$5,248.26	$5,458.19	$5,676.51	$5,903.57
5-year NPV of Costs	$97,210.10	This is the total cost over 5 years, adjusted into present value at Year 1 dollars to account for the time-value of money.			
Net Cash Flow	-$60,020.95	$16,124.21	$16,405.85	$16,690.39	$16,977.77
5-year NPV of Net Cash Flow	$1.54				
Summary					
GHG Reduction Equivalent ($/year)	$336.84	$350.31	$364.32	$378.90	$394.05
Energy Usage Savings (kWh/year)	538938.560				

Given the scenario created to assume a 5-year Payback Period, the following graph shows the Net Cash Flow of the project with Encelium. In the first year, there is a large capital investment to install the DDC system, and in later years the benefits gradually pay back the initial outlay.

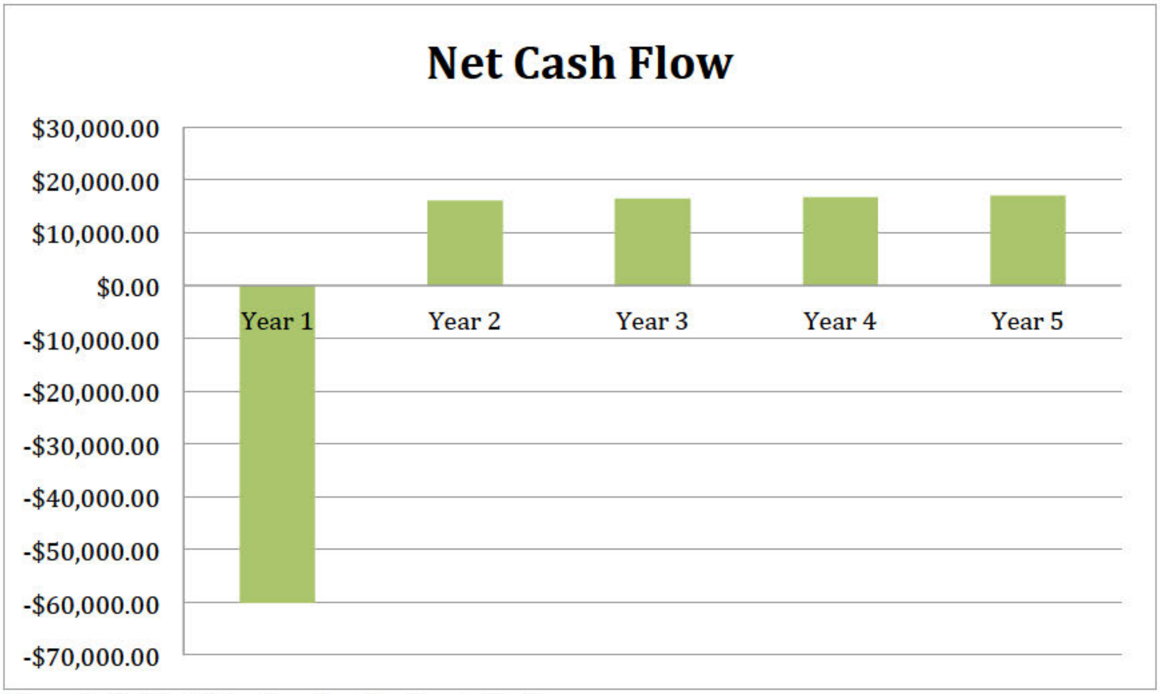

Figure 4. Net Cash Flow based on Encelium's Solution

Finally, of the room types, it was determined that lab spaces are the best candidates for energy savings using DDC because they are large areas with many lights near windows. This makes labs ideal candidates for saving energy using Strategy 1.

One of the greatest challenges faced has been comparing the vendors objectively because the next student who continues this project should be able to reproduce the same results. To overcome this, a scale and a rubric have been developed for scoring the products quantitatively in different categories and weighing those categories by the level of importance to UBC.

One barrier encountered has been finding the required information from all five businesses to perform the evaluation and because online contact information I not always available, and sales engineers have not yet replies to email inquiries. A solution to this obstacle involves seeking information from contacts with whom UBC has already established relations, using a professional IEEE email address, an calling the companies' headquarters to establish rapport before sending questions. As a result, several cost assumptions were made.

Out of this project, several areas of further study and analysis have been identified. These include:

- Determine the general hours a building is required to have lights on and propose a scheduled on/off switching. Consideration of special zoning of lights in some rooms may be required depending on function of room.
- Determine areas (e.g. laboratories, classrooms, study spaces, offices, hallways) that receive sufficient ambient light to make it worthy of installing a photo sensor that will automatically adjust light levels.
- Determine rooms that require only minimal brightness and are currently receiving above required lumens (subject to UBC Technical Requirements for Interior Lighting)
- Apply methodology to other buildings on UBC campus (currently assumes layout similar to MacLeod)
- Compare products from vendors against their datasheets and other claims, such as power factor and distortion, once actual hardware is obtained
- Define energy saving parameters, provide information to vendors who are interested in conducting a potential energy savings report
- Analyze additional cost savings from reduced burn hours of lights (currently assumed in model to be negligible)

8. CONCLUSIONS

This report summarizes the feasibility of retrofitting buildings with DDC lighting control systems, the evaluation of five DDC vendors, and the analysis of energy saving strategies.

One main conclusion is that the cost of installation is very sensitive to how much granular lighting control UBC requires, as well as the cost per controller. Another major conclusion is that Encelium and Crestron should be further investigated to understand installation and maintenance costs, and as well as other companies that provide additional information and are evaluated well through the rubric.

Several recommendations are also made for future projects to extend the scope of this initiative, as the methodology and analysis can be extended with more detail if sufficient information is provided by companies.

9. REFERENCES

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10. APPENDIX

10.1 Evaluation Tools

After discussion with supervisor and consulting with Sustainability office we ranked the importance of criteria for the analysis of the five companies. The following three tables were used in the final method for evaluating the vendors.

Criteria	**Weight**
Background and Experience	2
Energy Savings	5
Compatibility	5
Power Factor	5
Installation Costs	3
Maintenance Costs	5

UBC Importance Scale	
5	Critically Important
4	Very Important
3	Important
2	Moderately Important
1	Of Little Importance
0	Not important

Rubric Model for Scoring Matrix
A 0 is assigned to any criterion that does not meet requirements.

	Excellent **5**	**Above average** **4**	**Average** **3**	**Below average** **2**	**Poor** **1**
Background and Experience	Credible and highly reputable, established by experienced founders.	Case studies/White Papers available. Good testimonies from multiple clients.	Has retrofitted schools. Few examples on website.	Minimal experience in retrofitting lighting systems for universities/colleges.	Website does not appear to be credible. Contact information is not available.
Energy Savings	Specific data provided, proven results from completed projects.	Critical issues and key problems supported by effective solution.	Key points clearly identified for energy savings. Cases occasionally referenced.	Little evidence for energy savings provided.	Incomplete research and documentation on claims.
Compatibility	Class 2 BACnet IP compatible. 2-way read/write communication. Compatible with other protocols ie. Modbus, LonWorks, Metasys N2, NiagaraAX	Class 2 BACnet IP compatible. 2-way read/write communication.	--	Class 1 BACnet IP compatible. Read-only communication.	Proprietary. Not compatible with Douglas Controls; WNG-2133 Gateway.
Power Factor	No PF distortion	$0.97<PF\leq0.99$	$0.95<PF\leq0.97$	$0.90\leq PF\leq0.95$	$PF\leq0.90$
Installation Costs	Effective installation plan to reduce costs, ie. pilot program,	Number of units minimized, conduit savings (eg. communications via power wires)	Only simple wiring required.	Minimum network layout customization allowed.	Fixed network topology, no allowance for customization.
Maintenance Costs	Effective and robust solution that requires minimal maintenance. Easy network modifications. Thorough variety of monitoring and feedback, can display building's real-time statuses on dashboard, plus extra features eg. security alert, flags set at luminaire end-of-life, etc.	Effective and robust solution that requires minimal maintenance, ie. various remote adjustments, data logging, status monitoring and generating reports on demand.	Software program capable of monitoring statuses.	Data logging feature available. Simple remote adjustments.	No data logging feature. Not a ver capable software program.

10.2 Net Present Value

The measurement of the net value of a project in today's dollar terms, by taking into account the time value of money. The time value of money is the fact that over time, $100 today could be invested (e.g. in a project, in the bank, stocks, etc.) and would be worth more than $100 five years from now. Given the time value of money, it is better to be paid $100 today rather than to be paid the same amount five years from now. Conversely, it is better to pay an expense five years from now than to pay the same amount today. Net Present Value adjusts the cash flows from different times into the same time period so that values can be appropriately compared.

$$NPV = CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \cdots + \frac{CF_n}{(1+r)^n}$$

10.3 Company Information Summary

Below is a summary table of information gathered from the two main companies, Encelium and Crestron.

Encelium	
Year Established	2001
Contact Information	David Weigand, [redacted] Two local associates from Lightworks represent Encelium: David Rawlings [redacted] Nicole Meints [redacted]
Experience/Projects	Founded by 3 building operations engineers Many projects and experience with universities (eg. North Arizona University)
Continuing R & D?	Yes, and interested in working with UBC.
BACnet Compatible?	Yes. BACnet Class 2 compatible. BACnet interface adheres to ANSI/ASHRAE standard 135-2004.
Proprietary or Open Protocol?	Open Protocol energy management system as it uses BACnet. (Although GreenBus II is proprietary.)
Harmonic Distortion, Power Factor	Claims to have no distortion since ballasts are not proprietary.
Installation	External power packs for devices is not needed. Special termination at end of channels not required. Automatic addressing of individual nodes. Pilot program: used for energy studies on energy saving strategies for a building. UBC will pay 50% to keep the installation.
-conduit fitting	Wiring can be exposed or conduit fitted.
-device to bus efficiency	1 Energy Control Unit handles up to 800 nodes.
Maintenance	Sensor module is compatible with any type

	of luminaire – good for future-proofing.
-software robustness, usability	Polaris 3D can generate energy consumption map/hotspots on every floor and adjustments can be made immediately. Can remotely program light system scheduling. Can remotely adjust device sensitivities (eg. timeout intervals on occupancy sensor.) Individual luminare burn hours/runtime are recorded, which can be useful for warranty issues. Connections of devices are clearly shown in software, useful for troubleshooting Can display energy savings in foyer using CarbonWatch
-extra features	Many more options, eg. set flag for emergency lights near end-of-life. Utilize capability of dimming and switching of lights as a silent alarm for all occupants in the building.

Crestron	
Year Established	1968
Contact Information	Mark Pellegrino, [redacted]
Experience/Projects	Long list of project history on website.
Continuing R & D?	Yes, and already working with UBC Media Services & IT.
BACnet Compatible?	Yes.
Proprietary or Open Protocol?	Open Protocol.
Harmonic Distortion, Power Factor	PF = 0.99
Installation	Power over Ethernet is used where power + data are passed on a single cable.
-conduit fitting	(refer to above)
-device to bus efficiency	Control up to 2 DALI loops, 128 ballasts
Maintenance	
-software robustness, usability	Can log data at desired frequency
-extra features	Override input for system failure

Additional information on Encelium

Encelium indicates that they use six energy saving strategies:

1. Smart Time Scheduling, can schedule individual lights or a zone of lights
2. Daylight Harvesting, use photo sensors to automatically adjust light levels to allow more ambient natural sunlight, dim artificial light
3. Task Tuning, BM can set default cap for occupants storage rooms or hallways require less light than offices
4. Occupancy Control, occupancy sensors switch and dim lights based on activity
5. Personal Light Control, occupant satisfaction
6. Variable Load Shedding, shed low priority areas first during periods of high consumption or high energy pricing

The energy management software used is Polaris 3D^{TM} which is web-based. It has 3-dimensional view of a building, and all floor plans can be seen. Statuses of luminaires can viewed at any time, reports can be produced instantly on demand, and a pie chart showing percentage savings on the six strategies can be generated at any time. The software monitors progress, provides feedback on how to save energy further by tweaking strategies. Gradient view showing location of high energy consumption.

Additional information on Crestron

- Crestron already has equipment with UBC and has established relations with UBC's Information Technology Department and Facilities Management staff. The Crestron representative named Shaun Filwok and Claudio Pini from Media and Classroom Services as contact persons regarding Crestron equipment.
- Crestron uses BACnet Class 2.
- Crestron builds control processors that monitor conditions and uses logic to perform switching and dimming. They don't have a pilot program but will offer list price/manufacture price less 25%.
- They need UBC's energy savings parameters and a well-defined project scope

- Unlikely need to upgrade server, as information comes in low-level bytes. It does however depend on what UBC wants to monitor and how frequently
- In terms of doing an energy study for potential energy and cost savings with their systems installed, Crestron can install a monitoring system to survey consumption.