ZNE Retrofit Pathway for a University Recreation Center Complex: Deep Lighting Energy Savings Provide Important Step to ZNE

Karl Johnson, California Institute for Energy and Environment, UC Berkeley
Andrew Riley, Bill McTague and Gary Jurich, University of California, Santa Barbara
Jeff Doll, California Energy Commission
Pedram Arani, California Lighting Technology Center, UC Davis
Bach Tsan, Southern California Edison

ABSTRACT

The California Energy Commission's State Partnership for Energy Efficient Demonstrations (SPEED) Program managed by the California Institute for Energy and the Environment (CIEE) collaborated with the University California, Santa Barbara (UCSB) and Southern California Edison (SCE) to integrate deep energy efficiency best practice retrofits with on site renewables with the goal of reaching zero-net energy (ZNE) for the 122,000-sqft UCSB Recreational complex. In 2007, UCSBs recreation center energy usage was roughly 2.2 million kWh and 237,000 therms per year. In December 2008 a 155 kW DC photovoltaic solar system was completed producing roughly 250,000 kWh per year.

In 2009 a ZNE design Charrette identified potential energy savings and estimated site potential for renewable energy and the SPEED program demonstrated a number of best practice lighting retrofits. In 2010 and 2011 detailed evaluation was completed consisting of modeling, potential energy efficiency and renewable measures, additional metering and monitoring of the complex. In 2012 and 2013 detailed retrofit lighting design specifications and bid documents were completed. The construction started in October 2013 and will be completed by mid 2014. The retrofit adaptive lighting design uses LED fixtures and wireless networked controls with estimated savings of at least 70%. Starting in mid 2014, the next phase will start for the design and specifications of the HVAC systems, plug loads, water and pool heating as well as additional renewable generation. Design specifications, bid documents and construction are planned for 2014-2015.

This paper illustrates the complicated process, integrated designs of best practice energy efficiency lighting retrofit systems, life cycle costs, savings, and benefits of adaptive LED lighting systems as well as lessons learned and market barriers to meeting the ZNE retrofit design goals.

Introduction

In 2007 the University of California at Santa Barbara (UCSB) Student Affairs (SA) Department developed zero-net energy (ZNE) goals for all of the facilities they managed. Announcing these ZNE goals, especially for retrofits of existing buildings, was very unusual at that time but ZNE projects are now starting to grow (NBI, 2014). The first facility for ZNE retrofit was the Student Recreational Center Complex (SRC) and SA initiated an overall plan for incrementally installing solar photovoltaic's (PV) to partially power the complex using funds provided by the UCSB students as part of an integrated plan for renewable energy and deep energy efficiency retrofits. In December 2008 a 155kW solar PV array was installed which was primarily a student funded project with contributions from the Student Fee Advisory Committee, the office of the Vice Chancellor for Student Affairs, and the Recreation Center Student Fee Account. There was initial resistance from the campus, as the PV was considered unsightly at that time and there was a sense that the array should be mounted flat and concealed behind parapet walls. The intervention by Walter Kohn, a Noble Laureate in Physics allowed the construction of the array without a shielding parapet wall and with the modules above the horizontal mounting requirement. Since then the campus is now much friendlier to solar arrays and the 'form follows function' requirement of PV arrays. The SRC PV system and the strategy of "some PV first" verses energy efficiency first, also faced significant resistance. Yet this approach has proved effective in mitigating the SRC electric energy costs, limiting the risk of energy cost increases and gaining campus support for the PV systems and overall ZNE goals.

In March 2008 the SRC purchased and began using thermally insulated pool covers on all pools and reduced natural gas consumption between 35% and 40% annually in March 2008. Payback on this effort was a matter of two to three months.

In 2009 The SPEED program began working with SA and demonstrated task/ambient office lighting, bi-level stairwell lighting and combined daylighting and occupancy sensing controls at the SRC (CIEE, February 2011). The UCSB/SPEED program also invited collaboration and support from campus electric utility provider Southern California Edison (SCE). The SCE support lead to a design charrette in 2009 and continued partnership between the three organizations throughout the ZNE retrofit process.

An overview of the SRC facilities energy use, available renewable power, and potential energy efficiency measures were prepared for the 2009 design charrette with 19 expert participants (SCE, 2009). The charrette highlighted the need for deep energy efficiency of at least 60%-80% to be able to provide for the on-site renewable generation with the available roof space. It also highlighted the need for integrated plans; more detailed monitoring of end-use energy and iterative integrated designs to reach the ambitious ZNE retrofit goals. The gas use was primarily for the pool heating and the electric use was primarily for lighting and pool pumps. The need for very deep energy savings highlighted the shift in strategy needed for reaching ZNE goals verses incremental energy efficiency goals. Starting with the lighting systems, the goal was to reach 60% - 80% savings with one retrofit project, rather than taking the standard approach of short paybacks for lighting retrofits that save 30%. To meet the SRC ZNE goal requires two or three standard projects to reach the deep savings needed and cost significantly more due to the repeated projects. The CPUC "2010 Lighting Technology Overviews and Best-Practice Solutions" demonstrates the savings from best practices for 6 different lighting applications (CPUC 2010 LTO)

Another key aspect of the SRC's mission and operations is that the facility and equipment are continually changing to meet the needs of the students and operates all year long with the exception of several weeks during the year. Thus the team decided to continue to add sub-metering and develop detailed computer modeling of the SRC facilities. Also in 2009 both of the SRC Olympic sized pools were closed and replaced. New variable frequency drives (VFD) were added to control the pool pumps. The VFDs should have provided significant electrical savings, but were not properly commissioned and over time began to operate nearly continuously. The sub-metering from SCE in early 2013 helped identify this problem and the VFDs were re-commissioned in late 2013 with expected savings of 300,000 kWh/yr.

Starting in 2010 the focus was on refining the various end-use efficiency measures and on-site renewables that could be integrated into a system that would reach the ZNE goals. SCE sponsored a much more detailed analysis of over 28 energy efficiency measures that were summarized in February 2012. In 2011 the implementation activities for the best practice retrofit lighting and control systems for the SRC facility started with lighting audits, analysis, design, bid specifications, cost estimates and the implementation plans. The results of lighting retrofit analysis and implementations are elaborated in this paper. The additional sub-metered end-use data collected in 2013 is also being used to re-calibrate the SRC hourly energy simulations to provide the most accurate data for the evaluation of the individual and integrated systems for the HVAC, plug loads, water heating and pool heating. The next phase of the SRC ZNE retrofit is the iterative retrofit design process for the HVAC, plug loads, water heating and pool systems, which is not elaborated in this paper and will start in 2014 and implementation is planned for 2015.

Figures 1 and 2 below summarize the gas and electrical use for the UCSB SRC total and for the two main buildings Recreation Center 1 and Recreation Center 2 for 2007, 2010 and 2013. These figures illustrate the difficulty of establishing energy baselines with facilities that continually add and change equipment and features to the facility. It also highlights the need for more detailed end-use sub metering that allows better understanding and management of the energy use. Sub metering data and analysis is particularly important for understanding how to reach ZNE goals and how to maintain the ZNE operation on an ongoing basis. This is illustrated pointedly by not originally monitoring the pool pump VFD to validate proper operation. The addition of the sub metering and analysis identified the improper operation of the pump that consequently added roughly 300,000 kWh to the 2013 electricity use.

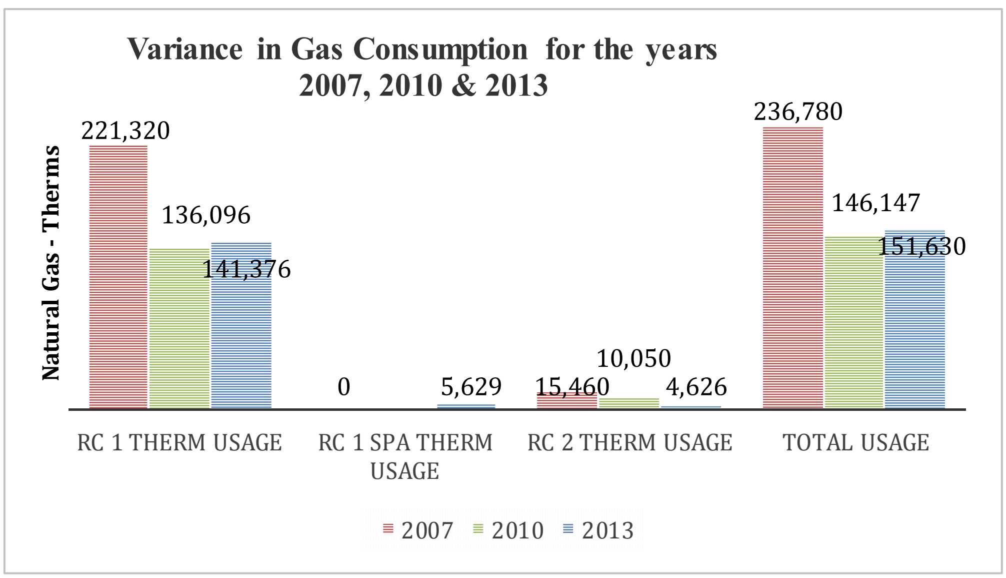

Figure 1. UCSB SRC gas consumption summary for 2007, 2010 & 2013.

The increase in total gas usage between 2010 and 2013 for the Recreation Center is, in large part, due to the installation of a spa pool in early 2011. In general, gas usage has remained consistently lower since the use of pool covers began in 2008. The gas usage for the SRC non-pool heating end uses of HVAC and domestic hot water is approximately 20,000 therms annually.

Figure 2 shows the electrical use for the SRC for 2007, 2010 and 2013 as well as the energy generated by the solar PV system. The increased electrical use for 2013 is due to the pool pumps operating continuously from the malfunction of the VFD controls on the pool pumps. The lighting retrofit started in October 2013 with the emergency replacement of 76 high bay LED fixtures in the Rec 2 Multi Activity Center (MAC) gymnasium. The sub metering of the lighting systems is documenting the energy savings achieved by the replacements. With the majority of the lighting being completed by mid-2014 and the VFD pool pump operating properly, the electric savings should also be documented by the overall SRC meters

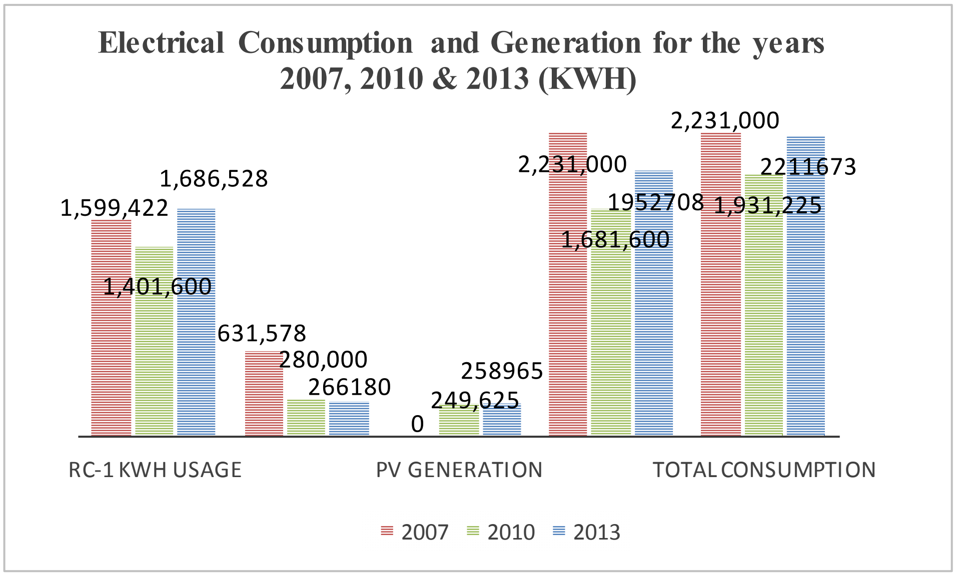

Figure 2. UCSB SRC electricity consumption summary for 2007, 2010 & 2013.

Overview of SRC Lighting Retrofit Analysis, Savings, Economics and Implementation Results

The following section summarizes the results for the SRC ZNE lighting design, analysis and estimated economic results. In August 2013 one of the SRC metal halide high bay fixtures catastrophically failed with an electrical short that burnt through the safety cable and fell to the gym floor. This was a significant safety hazard and required emergency action to replace all of the high bay fixtures. Since the specifications for the interior lighting retrofit were completed, the campus used them for the emergency SRC lighting replacement. The design was also evaluated and optimized to reduce the number of high bay fixtures and still maintain the needed lighting levels. The dimming controls also allowed the tuning of the lighting levels to match the changing program needs. The silver lining of this event was the shift to using UCSB staff to replace the fixtures using the ZNE lighting retrofit specifications. The results of having UCSB labor install and commission the lighting system as well as managing the LED and controls procurement process was to dramatically reduce the original estimates for the retrofit costs based on the typical campus request for proposals (RFP) bidding and contracting process. Figure 3 shows the estimated savings and Figure 4 shows the costs for the different approaches. The ZNE lighting retrofit using LED fixtures and wireless networked controls with tuning, occupancy and daylighting controls will save 75% of the electrical consumption for the interior and exterior SRC lighting system. The majority of the control savings is from tuning and occupancy. Figure 3 also shows the estimated savings from the re-commissioned pool pump VFD and preliminary estimates for the future retrofits for the field lighting, HVAC and plug loads. These will be optimized with further analysis and are not covered in detail in this paper

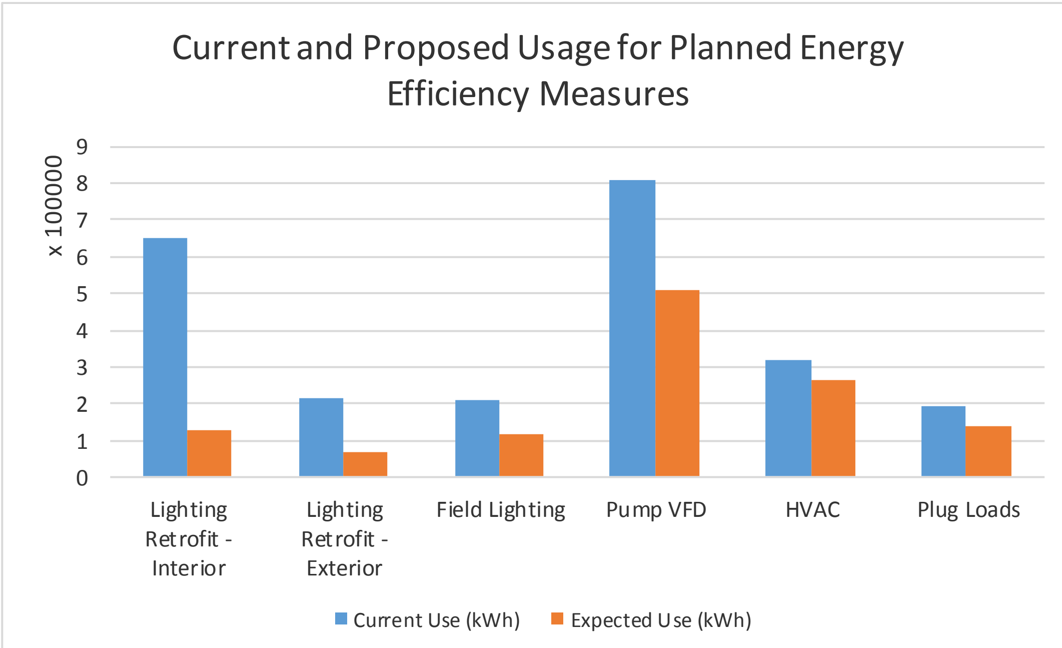

Figure 3. Estimated savings for various planned energy efficiency measures highlighting significant lighting loads.

Initial SRC lighting retrofit efforts have focused on the interior lighting, which, prior to starting the retrofit project in late 2013 consumed roughly 630,000 kWh annually. Initial estimates for the best practice LED and wireless controls retrofit a reduction of roughly 75% or 450,000 kWh per year to an annual use of 150,000 kWh. These estimates were based on a lighting audit and subsequent schematic design by P2S Engineering, supported by extensive research and design optimization from the ZNE team and SPEED Program. Similar reductions of 60% to 80% are estimated with the exterior and pool lighting project. Next to the SRC is a large student recreational athletic field, which was not part of this project. Yet in the near future advances in high output LED fixtures for field lighting are emerging and will be most likely be more economical and installed in late 2014

The emergency in-house replacement of the high bay gymnasium fixtures using the ZNE lighting retrofit designs and specifications was so successful that they decided to continue the in-house implementation for the entire SRC interior and exterior lighting. Figure 4 and Table 1 show the cost comparisons for the different implementation approaches. These show that the typical request for proposals (RFP) bidding process was estimated to cost $1.13 million while the in-house process is expected to cost $590,000 saving roughly 50%. Using the expected 75% savings, the in-house implementation reduced the estimated payback and ROI from 22yrs to 10 yrs and 14.1 to 4.3 ROI respectively. Table 2 shows a detailed comparison of the costs. Not only are some of the costs of an RFP process unnecessary with an in-house implementation, but there are significant savings in the construction phase. The in-house installation savings are primarily from the design optimization, in-house labor and managing the procurement process. The typical barrier of cost mark-ups for new technologies by designers, distributers and contractors was effectively managed using the in-house implementation. Even when an RFP process is necessary, it is important to carefully manage the design, procurement and installation process to assure optimal value. New technologies usually face a market barrier of added costs by the designers, distribution system, and installers. The SRC lighting systems faced these added cost barriers and careful management of these barriers can significantly reduce the implementation costs.

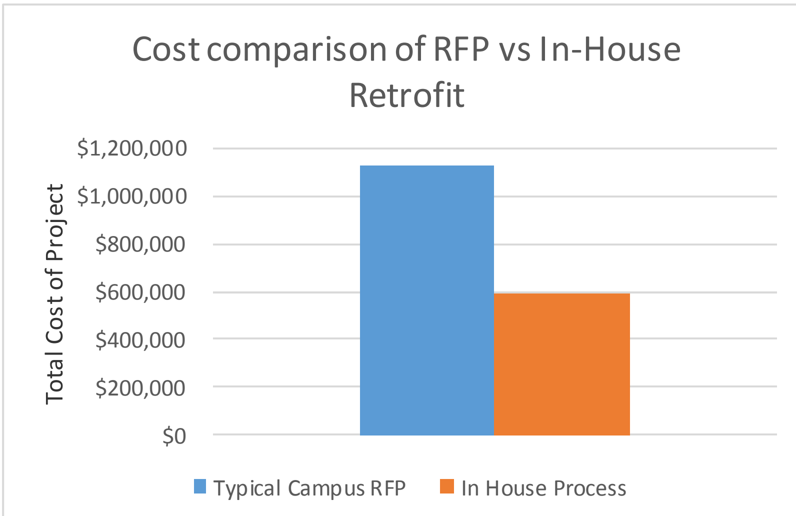

Figure 4. Cost comparison for the SRC interior ZNE lighting retrofit of the typical RFP bid process versus in-house implementation.

Table 1. Cost analysis comparing typical RFP vs in-house implementation for the interior lighting and controls UCSB SRC retrofit

Cost Analysis – Standard RFP compared to In-House Implementation of lighting retrofit		
	RFP Budget Estimate	In House Implementation
Schematic Design Phase		
Peer Review/Cost Estimate/Drawings	$41,900	$41,900
Schematic Design Phase	$5,700	$5,700
Construction Document Phase		
Construction Drawings & Bid Package	$45,200	
Drawing Review & Bid Package	$7,000	
Bid & Award		
Bid Prep & Award	$5,000	
Printing/Shipping/Advertising	$3,500	
Construction Phase		
Construction Contract	$1,020,000	$680,298
Construction Contingency @ 10%	$102,000	
Construction Inspection,	$18,000	
Construction Project Management	$10,000	

Project Close Out Project Close & Warranty Period	$6,000	
Total Budget Funding approved to date Additional funding required SEP Incentives credit	$1,264,300 ($47,600) $1,216,700 ($90,130)	$727,898 ($47,600) $680,298 ($90,130)
Project Total Under Each Scenario	$1,126,570	$590,168
Simple Payback in years based on 75% energy reduction	20.0	10.2
Simple Payback with life cycle cost reduction* in years based on 75% energy reductions	14.1	4.3

*Life cycle costs include materials only and assume 830 fixtures with an average lamp cost of $120 per fixture for a total of $300,000 for 3 re-lamping cycles over the lifetime of the LED fixtures. Labor is assumed to be avoided cost and valued at $160,000 assuming one half hour per fixture at $65/hr over 3 re-lamping cycles.

Summary of Energy Saving from Lighting Controls

Figure 5 below shows the savings for the 69 (of the 76) high bay 200W LED fixtures and controls for the MAC Gym. 76% overall savings for the February 2014 are shown on the graph. The majority of the control savings come from task-tuning the LED fixtures down to 50% of maximum output, shown in the light blue in the graph. Even with the 50% tuning reduction proper lighting levels were maintained for typical activities. Yet the lighting can be increased for special events. The occupancy sensing savings shown in green were roughly 40% of the controls savings as is shown in green. Occupancy sensors are very effective for both typical occupancy savings and for reducing the common override issues that plagued the system. The most common issue was when the custodial staff would enter the spaces after 2am and manually override the sweep set in place with the old control system, which often left the spaces lit until 8am the next day when staff would turn them off again. The controls also make use of the excellent day lighting provided by the clearstory windows in the gym spaces saving 10% shown in yellow in the graph below.

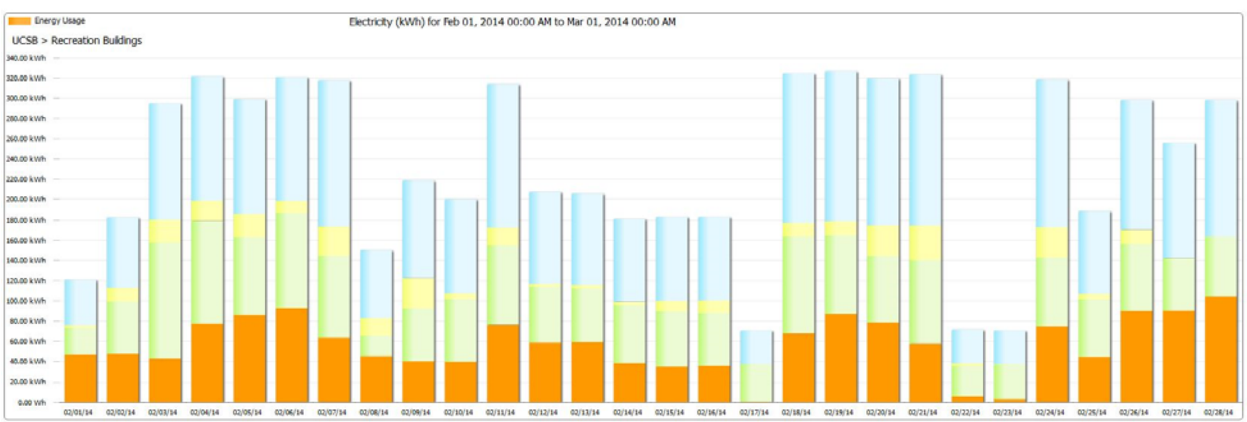

Figure 5. Summary of energy use and sources of reductions for the MAC Gymnasium highbay lighting for the month of February – screen shot of the networked controls dashboard.

The true power of utility grade sub-metering installed also showed a significant improvement of the power factor with the LED fixtures due to a reduction of reactive loads compared to the former HID fixtures. Also, networked controls dashboard identified an unexpected problem with the legacy lighting controls systems disabling the new-networked controls. In this example, the SRC cleaning crew overrode the old system control to turn the lights on and this action also disabled the new-networked controls so they did not turn the lights off when the cleaners left. Another example of a problem identified with the networked controls is when people use existing light switches and turn off the lights, this also disables the networked controls thus removing the light switches became necessary.\

Importance of Emergency Lighting

An unexpected and key lesson learned is that the energy used by emergency fixtures becomes a significant lighting load after deep energy retrofits. Controlling emergency lighting is allowable by codes and important for reducing unnecessary energy use especially for ZNE operation. After the deep energy savings from the ZNE lighting system, the 7 (out of 76) emergency lighting fixtures that were not controlled now consumed 43% of the total lighting use for the gym area. The controls are installed on the emergency high bay fixtures but since emergency fixtures are traditionally not controlled there is still significant resistance to approving controlling them. The team is working with all the various code and campus agencies to resolve the concerns, clarify the code requirements, and start to properly control the emergency fixtures. Table 2 shows the energy use for one of the Recreation 2 Multi Activity Center (MAC) gymnasiums new LED high bay lighting using wireless networked controls

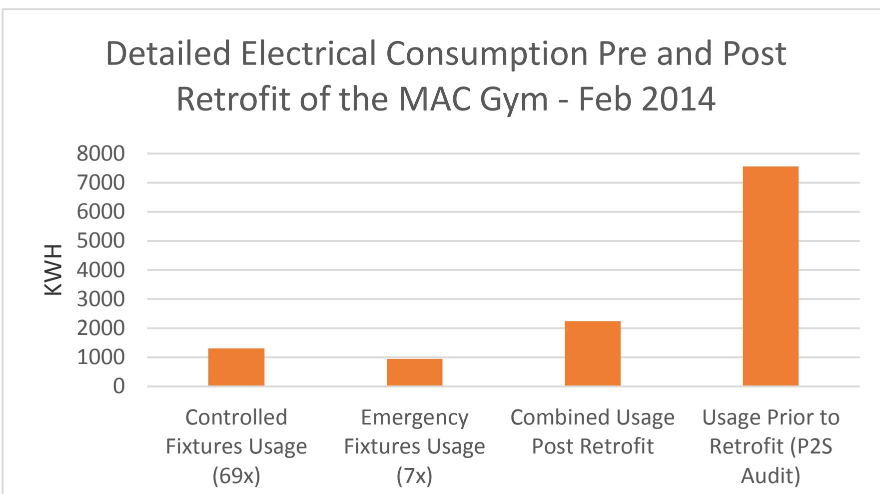

Figure 6. Energy use comparison for uncontrolled emergency fixtures versus controlled fixtures in MAC gymnasium.

Lessons Learned

There are many lessons learned from this innovative early adaption of ZNE retrofits for a campus recreation facility that can be useful to many other ZNE projects. These lessons cover the overall vision, planning, strategies, iterative and integrated planning, serendipity, implementation approaches, communications, and essential need for end-use metering for ZNE operations. Highlighted below are some of the key lessons learned:

- There are many barriers to the vision and implementation of ZNE retrofits including; the lack of industry knowledge of state-of-the-art best practices, the fact that integrated design is uncommon especially for retrofits, the focus on first costs, use of simple payback verses life-cycle economic evaluation, standard strategy of low-hanging fruit verses deep energy savings. There are also a host of barriers to the adoption of new best practice technologies including the conservative nature of designers, specification writers, suppliers, and installers that can often add significant unnecessary costs to the ZNE projects. (CIEE, February 2012). Many of these barriers can be overcome by setting the ZNE goal as paramount with great communication, collaboration and careful management of the entire process.
- The overall strategy for a ZNE retrofit project has a specific goal of zero net energy and is different from the standard approach of incremental savings retrofits. California and many campuses have ZNE goals within the next 10 – 15 years (Paper 885, ACEE 2010) and the best strategy for reaching these goals is to achieve the most savings possible from one retrofit project using the current best-practices for integrated systems. The first costs of the SRC lighting systems retrofit are significantly more when compared to the typical standard lighting retrofit. But that comparison is misleading and incorrect for ZNE goals because the ZNE goal requires 60%-80% savings. The standard approach takes 2 or 3 retrofits to get to the same goal as one retrofit of best practice lighting and costs more and saves less. Over a ten-year period best practice lighting saves twice as much energy as standard practice lighting (CPUC, 2010). In the short time period to meet the ZNE goals you only get "one bite of the apple".
- The dimming and networked controls enable the tuning of the lighting systems to match the customer needs and IES requirements and can be easily changed to match different lighting needs. For several different SPEED demonstration projects including the UCSB SRC the lighting levels were tuned down by 50% for typical activities and tuning was the largest part of the control savings; larger than occupancy and daylighting savings. The tuning savings were key to maximizing the energy savings, maintaining the recommended lighting levels for typical activities, and providing the capability to increase lighting levels for special activities. Therefore, integrated adaptive lighting systems with networked controls result in the deepest energy savings, operations and maintenance advantages, and are typically the best investments for ZNE projects.
- The old adage of "you can't control what you do not meter" is aptly applied to ZNE projects especially for the persistence of ZNE operation. For the SRC the integrated lighting system used dimmable LED technology with wireless adaptive controls that also included monitoring and metering of the energy use. The usefulness of monitoring and operational data is exemplified by the SRC retrofit. After the LED and controls retrofit was completed the networked controls monitoring showed that the seven emergency high bay fixtures that were not being controlled now used almost 43% of the overall monthly electricity for the gym lighting. The electric and building codes allow for controls on emergency lighting as long as the egress foot-candle levels are maintained. Without the incremental monitoring of each high bay fixture this savings opportunity would not have been obvious. The initial resistance to new technologies now able to reliably control

emergency lighting is common due to the safety concerns. This resistance to controls on the emergency lighting is another example of a market barrier to new technologies.

- The digital LED technology is revolutionizing the lighting industry and the integration of controls with monitoring is now emerging and will become the norm for deep energy efficiency and ZNE projects. The availability of dimmable LED and control technologies is rapidly increasing while the prices of these digital technologies are dropping rapidly. The LED lighting technologies are basically following a similar path to Moore's Law that essentially says that computer integrated circuit technology will be half the price in two years and new versions will have twice the performance at the same price.
- When retrofitting the lighting systems it is important to carefully evaluate the interactions with any existing lighting controls to make sure that they do not interfere with the expected operation of the new controls.
- Many of these lessons learned will apply to the next phase of the project and the future retrofits for the field lighting, HVAC and plug loads.

Conclusions

There are still many market barriers to implementing ZNE retrofits for campus Recreation Center complexes as well as other buildings. Yet, the ability to cost effectively create ZNE buildings and communities exists now with technologies and systems that are currently available for both new construction and retrofits (NBI, 2014).

Meeting ZNE or Sustainability goals within a short 10 to 15 year time period, like the California ZNE and UCSB Sustainability goals, require a shift in strategy. The shift is away from the standard approach of incremental evaluation of energy efficiency, demand control and renewables with the focus on first costs and short payback periods. The shift required is toward developing integrated strategies to dramatically reduce energy use, control peak demands and integrate renewables to meet the ZNE goal within a set time period. This paper illustrates the ZNE strategy shift in many ways. First the leadership sets the primary objective to reach ZNE goals. Therefore the overall energy use reductions along with the availability of onsite renewables are defined and set the overall integrated strategy. This causes a careful evaluation of the standard approach and allows for flexibility in the ZNE implementation strategies.

Second, the strategy to achieve the deep energy savings goals for the SRC to achieve ZNE required using best practice technologies and system integration. Using the lighting retrofit as an example, the initial UCSB proposal for the lighting retrofit consisted of a standard lighting upgrade that improved the high bay lighting and reduced the gymnasium lighting energy use by roughly 35%. With ZNE as the end goal, the entire lighting system needed to reduce energy consumption by 60% to 80% in less than 15 years. Thus, the standard approach would require multiple separate retrofits to meet the ZNE energy use requirements. With best practice lighting technology and controls, the SRC lighting energy use was reduced by 70 % to 75% in one retrofit project not three or more projects. The deep energy efficiency strategy will also apply to the energy loads not covered in this paper, which focuses on the lighting system retrofit.

Third, the strategy for installing some PV renewables first was developed within the integrated ZNE plan. Starting with some PV first had many advantages; It stabilized the energy costs, limited the risk of increased electricity rates and provided better economic returns than having the capital in the bank. Equally importantly, the PV system was a visible symbol of the shift to ZNE and helped galvanize the students and campus to support the adoption of more PV and ZNE buildings.

Finally, some other conclusions from the UCSB ZNE SRC project experienced to date are that having the ZNE goal and integrated framework in place early in the process enables incremental implementation allowing optimization of investments; dimmable and networked lighting control systems provide for easy commissioning; managing and monitoring energy use is essential for meeting and maintaining ZNE operation. Additionally, there are numerous ways to effectively manage the various market barriers to implementing new best practice technologies and systems including carefully managing the design and procurement process to avoid unnecessary mark-ups, using in house staff for implementation and commissioning, and using the networked end-use sub metering for verification and to maintain the integrity of the ZNE goals.

References

2014 Getting to Zero Status Update, January 2014, New Buildings Institute, http://newbuildings.org/sites/default/files/2014_Getting_to_Zero_Update.http://newbuildings.org/sites/default/files/2014_Getting_to_Zero_Update.pdf

California Institute for Energy and the Environment, February 2011. Final Project Report: PIER Demonstration Program: State Partnership for Energy Efficient Demonstrations 2004-2010, California Energy Commission, 2011, at www.energy.state.us (pending)

California Institute for Energy and the Environment, February 2012. Final Project Report: PIER Demonstration Program: State Partnership for Energy Efficient Demonstrations 2010-2012, California Energy Commission, 2011, at www.energy.state.us (pending)

Developing a Strategic Lighting Plan: Lessons from California's Efforts to Transform the Lighting Market, August 2010, Paper 885, ACEEE Summer Study 2010

2010 Lighting Technology Overviews and Best-Practice Solutions, August 2010, California Public Utilities Commission, CIEE Research Contract CP1- 010, http://uc-ciee.org/energy-use-in-buildings/strategic-planning-for-lighting