CALIFORNIA ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Leading in Los Angeles:

Demonstrating Scalable Emerging Energy Efficient Technologies for Integrated Façade, Lighting, and HVAC Retro-commissioning

Gavin Newsom, Governor

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Project Team:

nbi new buildings institute

TRC Results you can rely on

BERKELEY LAB

Demonstration Site Partners:

The City of Santa Ana

California State University Dominguez Hills

Manufacturers and Product Partners:

ROLLEASE ACMEDA PRECISION IN MOTION

BeMotorized

Daintree ONE

Technology Transfer Partner:

the Energy Coalition

Installing Contractors:

lumenomics

SBT

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Leading in Los Angeles is the final report for the Leading in Los Angeles project (Agreement Number 16-032) conducted by New Buildings Institute. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

Existing buildings represent an immense challenge for California to meet its ambitious climate goals. To address the vast energy use and emissions associated with existing buildings that largely fall outside of the regulatory scope of local and state government, market attractive and scalable deep retrofit solutions are a vital part of the solution. The project team developed a low-disruption retrofit package made up of pre-commercial wireless solar-powered automated interior shades, upgrades to LED lighting with networked lighting controls, and HVAC retro-commissioning with a goal of achieving 20% whole building energy savings. The project team developed, tested, and piloted the retrofit package over the course of four years. The project upgraded of over 4,400 light fixtures and the installed nearly 1,000 shades in 220,000 square feet of office floor space at two public buildings in the Los Angeles area.

Laboratory testing at the Lawrence Berkeley National Lab's FLEXLAB facility showed 49-62% lighting energy savings in the daylight zone during occupied hours against a Title 24 baseline and 15-43% cooling savings in the summer and fall seasons. At the two demonstration sites, Santa Ana City Hall and California State University Dominguez Hills Welch Hall, the project team observed 15-26% whole building energy savings (35-42% lighting, 6-29% HVAC) during the post-retrofit period as determined by our M&V2.0 analysis.

As a result of this research project, the project team developed market resources to support the adoption of these retrofit technologies, including separate standalone guidance for owners, installers, and policymakers. The project also advanced the commercial viability and technology readiness of self-powered automated interior shades as a retrofit solution. The estimated statewide potential benefits to California are 2,000 GWh, $375M, and 1,750 million pounds of CO_2 per year.

Keywords: Automated Shades, Self-powered Shades, Lighting Retrofit, Luminaire-level Lighting Controls, Retrofit Package, Integrated Technologies, Retro-commissioning, Office Upgrades, Measurement and Verification

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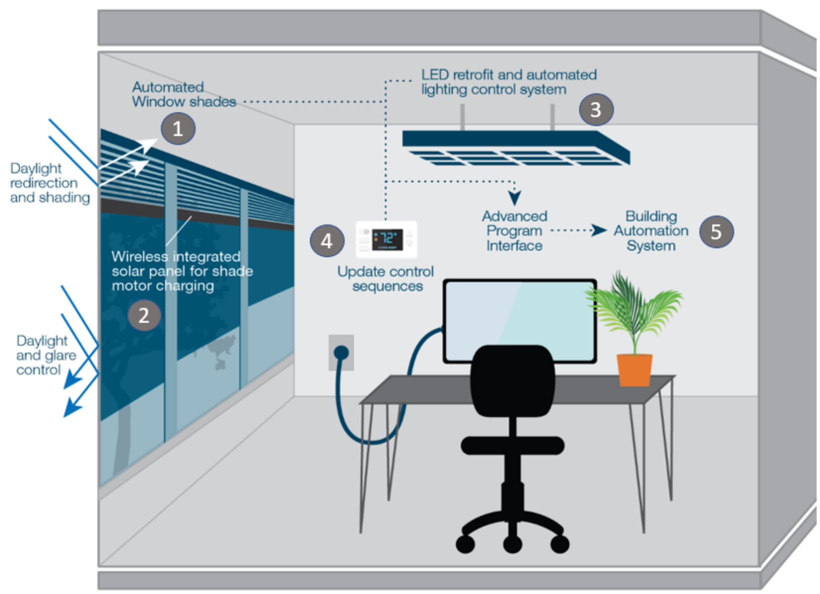
Introduction and Background

The Leading in Los Angeles (LiLA) project is a research effort in response to the critical need to greatly reduce energy use in the state's existing commercial buildings with cost-effective and scalable solutions, particularly in the Los Angeles Basin where energy constraints from the Aliso Canyon fuel leak were acute.

Launched in June 2017, the project efforts include a four-year combination of a lab test, field demonstrations at two office sites, and market connection efforts to move an integrated set of emerging commercial retrofit technologies into wider adoption.

The project focused on deployment of the INTER technology solution set. This retrofit package includes (1) novel automated interior shades with daylight redirection, (2) wireless PV-powered shade motors, (3) LED lighting with networked lighting controls (NLC), (4) minor HVAC retro-commissioning (RCx) to tune the building sequence of operations and bring them up to industry best practices, and (5) integration with the building automation system as shown in Figure 1. Lighting, HVAC, and miscellaneous loads make up most of a building's energy use (approximately 70% for a typical existing California office).

Figure 1: The INTER Technology Solution Set



Source: New Buildings Institute and TRC Companies

To meet California's climate goals, reducing energy consumption throughout the existing building stock is paramount to support a 100% clean energy future. Lower energy demand from buildings can alleviate the need for fossil-based power generation. Reduced energy demand from existing buildings will additionally reduce burden on existing energy infrastructure, including power distribution and transmission. The INTER solution set is designed to be installed with minimal disruption to building operations thanks to the wireless operations and quick installation time.

The current paradigm in the built environment is focused on an incremental, widget-based approach to energy efficiency upgrades. This approach misses a larger opportunity to drive down energy consumption and provide greater energy cost savings. For example, upgrading light fixtures in a building comes with direct and easily predicted savings, but misses the additional savings available from adding lighting controls and integration with other systems.

Project Purpose

This project seeks to develop and demonstrate the value of a packaged retrofit system that addresses multiple aspects of the building, including lighting, HVAC, and occupant comfort. The package is designed to have each technology work together in an integrated fashion. The INTER retrofit package, and research objective, was to provide 20% whole building energy savings. By proving out these savings with a scalable solution, we provide the market and ratepayers an attractive path toward significant energy reduction and cost savings. This solution is geared toward offices but could be applied in a wide array of building types, including schools, higher education, hospitals, and other types that have regular occupancy in the perimeter zones of their buildings.

The project aim was to promote this solution with the design and commercial real estate communities via trade publications, conferences, design guidance, and direct outreach in the Southern California region.

Project Team, Approach and Sites

The project team included New Buildings Institute (NBI), TRC Companies (TRC), and Lawrence Berkeley National Laboratory (LBNL). NBI led the overall effort as well as the technology transfer efforts. TRC pioneered the retrofit package design and managed construction at the two demonstration sites. LBNL tested the equipment in the lab and conducted the measurement and verification of the field findings.

At the onset of the project, the team formed a technical advisory committee (TAC) made up of industry leaders to review the project approach and offer feedback and guidance to the project team. As a result of that engagement, the project team extended surveys to the contractors and owner representatives and captured more quotes and photos used in the market materials. The TAC also encouraged the team to spotlight technologies individually and as an integrated package to raise awareness and to get the attention of designers and owners.

The project team tested the package at the LBNL FLEXLAB against two lighting configurations: an existing building and Title 24 standards. This testing measured lighting energy as well as heating and cooling demand reductions in three seasons: summer, fall, and winter. For the "real world" installation, the team selected two project partner sites that reflected standard baseline equipment in existing offices: Santa Ana City Hall (SACH) and California State University Dominguez Hills (CSUDH) Welch Hall.

The project team installed extensive energy monitoring equipment for detailed pre-retrofit data collection prior to overseeing the installation of the full retrofit package at the two demonstration sites. Our original length of study for M&V was significantly impacted by the abnormal occupancy during the shelter-in-place due to COVID-19. The post-retrofit period with normal occupancy was just 2 weeks in SACH and 10 weeks in Welch Hall. Additionally, there were some data gaps in the lighting data and post retrofit steam data at SACH. Despite these limitations, we were able to compute savings for the post-retrofit period with the retrofits fully in place at both sites. The project team analyzed the detailed pre- and post-retrofit energy consumption data to establish energy reduction estimates using RM&V2.0 protocols[1].

The building configuration and pre-retrofit lighting are shown in Table 1.

Table 1: Demonstration Site Descriptions

Owner	Building	Year Built	Building Size square feet (sf) and Floors	Primary pre-retrofit Lighting Type
City of Santa Ana	Santa Ana City Hall	1972	127,000 sf building Retrofit: 88,000 sf 8 floors + basement	2-lamp T8 troffers with Daintree lighting controls
California State University	Dominguez Hills Campus Welch Hall	2001	183,000 sf building Retrofit: 131,000 sf 4 floors	3-lamp T8 troffers with Enlighted lighting controls

Project Results

The research demonstrated the INTER solution set can meet the project goal of 20% whole building energy reduction. Technology advancement, particularly for the automated interior shades, is another key result discussed below. The final installation of technologies are shown in Table 2 and include upgrades to over 4,400 light fixtures and installation of almost 1,000 new shades with over 300 shades (32%) the emerging Illuminate product shown in Figure 1.

Table 2: Final Technology Installations Count by Site

Technologies	Santa Ana	CSU DH	Totals	Ratio of shades
Advanced Light Fixtures	2,413	1,989	4,402	n/a
Illuminate Shades[1]	142	164	306	32%
Automate Shades	2	37	39	4%
Manual Shades	337	271	608	64%
Total Shades	481	472	953	100%
RCx	Yes	Yes +[2]		

[1] *With daylight redirecting upper louvers* [2] *Additional control mods by Building Manager*

Laboratory Savings

The laboratory tested the automated shading products and LED dimmable lighting with daylight controls. The lab tested a full window and a slightly smaller window size and found little variation. In the full window measurement lighting energy savings relative to an existing

[1] RMV2.0 is an open-source package managed by LBNL for performing advanced energy measurement and verification for Commercial Buildings.

building baseline of non-dimmable fluorescent fixtures on scheduled operation ranged from 62% in winter to 76% in summer. Relative to a Title 24 baseline lighting system equipped with dimmable fluorescents and stepped dimming for fixtures near the windows, lighting energy savings were naturally reduced, but still ranged from 50% in winter to 62% in summer. HVAC cooling load savings were very close to lighting energy savings in absolute terms. Summer and fall HVAC cooling load savings were consistently higher than energy savings from lighting alone on an absolute basis, indicating that the INTER automated shading also contributed energy savings, likely due to solar heat gain reductions from the shades.

Table 3: INTER System Laboratory Savings at LBNL FLEXLAB

Savings Area	Base Case	Summer	Fall	Winter
Lighting	1. Existing building: T8 (1.0 W/sf), no dimming; manual blinds	10.8 (76%)	10.4 (73%)	9.0 (62%)
	2. T24: T5 (0.69 W/sf); stepped dimming; manual blinds	5.3 (62%)	5.0 (57%)	5.0 (50%)
Cooling	1. with T8 lighting	11.0 (36%)	10.9 (28%)	--
	2. with T5 lighting	6.0 (19%)	6.5 (15%)	5.9 (26%)
Heating Savings: Some HVAC load penalty (negative savings) was observed in heating mode, as expected. However, little time was spent in heating due to the test site's climate, so results are less robust.				

Measured Energy Savings

Whole building measured savings during the fully occupied monitoring period were 26% and 15% in Welch Hall and SACH respectively as shown in Table 4. The Welch Hall savings includes additional HVAC controls measures that were initiated by the facility manager outside of the scope of the INTER retro-commissioning work. Conversely, the SACH savings are an underestimate because they did not include district steam savings due to an unresolvable data anomaly in the post-retrofit district steam data.

The site energy savings we did observe were strong, and the laboratory tests suggest that savings based on the season of our occupied monitoring alone (winter and early spring) would underestimate total energy savings. Furthermore, the laboratory tests were done in a Bay Area climate and the cooling load savings would be amplified in southern California climates.

Taken together, the results from the sites and the laboratory suggest that the INTER system can reasonably be expected to provide the target annual site energy savings of 20% in both Welch Hall and SACH and in other existing buildings[2].

The lighting upgrade to LEDs with controls responding to occupancy and enhanced daylighting resulted in significant energy reduction. Lighting energy use savings during the monitoring period were 35% and 42% in Welch Hall and SACH respectively as shown in Table 4. Based on

[2] Existing buildings that have not updated to LED lightings and network controls. As always, savings for any given building can vary considerably.

seasonal variation in lighting energy reduction observed during the lab testing, we estimate these lighting energy savings to be a reasonable annual estimate. We are not able to generalize HVAC savings to an annual basis due to the limited weather conditions observed.

Table 4: Measured Energy Savings Compared to Pre-Retrofit

Building	Total Site Energy	Electricity	Lights	HVAC
Welch Hall	26%	15%	35%	29%[1]
SACH	15%[2]	19%	42%	6%[2]

[1] Welch Hall HVAC savings include modifications beyond the research RCx scope implemented in parallel by the facility manager.
[2] Santa Ana site total and HVAC savings do not include savings in district steam, due to erroneous data. These figures represent electricity and chilled water savings only, so savings are likely larger.

Electricity and Cost Savings

Although actual final savings for the two demonstration sites will likely vary with changes in occupancy, space use, and other factors following a return to full occupancy change, we estimate the kilowatt hour and costs savings shown in Table 5 based on the annual lighting energy savings projections. HVAC annual savings were not able to be calculated due to a lack of seasonal change as described in the preceding section. From the lab findings the cooling savings are potentially close to that of the lighting thus energy and cost savings are greater than indicated below.

Table 5: Projected Annual Lighting kWh and Cost Savings by Site

Location	Lighting kWh Savings	Lighting Energy Cost Savings ($)
Santa Ana City Hall	200,000	$18,000
CSUDH Welch Hall	170,000	$14,000

Technology Advancement

The project encountered numerous installation and performance challenges due primarily to the limited technology readiness of the novel automated shades. The controls for the shades were not yet fully developed and the integrated PV panels that charge the shade motors were not providing sufficient power to maintain adequate battery charge for normal operation in north-facing locations and areas with solar obstructions (trees, overhangs etc.).

To resolve this lack of functionality for the demonstration partners, the project team engaged a third-party vendor to develop the shade controls and worked with the manufacturer to install an interim solar panel to establish fully functional shade systems at the sites.

The technology issues were found and assessed through the research and resulted in product evolution that will benefit future production, reliability and market adoption as follows:

- **Shade controls developer expands offerings and becomes product partner.** An emerging vendor of automated shades controls provided the control technology and remote access and performance data. BeMotorized (BeMo) is now a formal partner with the shade manufacturer (Rollease Acmeda) to provide reliable cloud-based control for occupants and operators.

  - BeMo's subscription-based model parallels new trends for building integration companies that take responsibility for monitoring equipment and providing real-time data and fault-detection through the building automation or energy information system for the operator. The research advanced the 'software-as-a-service' (SAAS) model and expanded the market for a growing controls vendor who is well connected with commercial real estate in California.

- **New Gen4 PV panel in development and testing for market deployment in 2022.** The project identified that the PV panel supplying the batteries power to the automated shade motors did not provide sufficient power in locations with limited or obstructed solar access. This wireless solution is a critical part of impacting the existing building market for automated daylight redirecting shades with integrated advanced lighting controls. The manufacturer (Rollease Acmeda) plans a new more robust PV panel in production in 2022 due to this research.
- **Technology Readiness Level (TRL) increases for automated shades.** Two emerging products components evolved to be more technically and market reliable due to the demonstration application and research findings. Automated shade controls moved from a 5-6 TRL to a 7-8 TRL and the shade integrated PV-panel power supply has moved from a 4 TRL to a 6 TRL.

Technology and Knowledge Transfer

The INTER solution set is targeted at two primary market types – offices and schools – where the systems in most existing buildings lack the energy efficiency, operational, and comfort attributes of the leading technologies demonstrated in this research project. These two markets, further distinguished by size as shown in Table 6, represent approximately one third of California's commercial building space and electricity consumption.

Table 6: California Floor Space and Electricity by Target Market

Sector	Floor Space	Electricity
Small Offices (<30,000 sf)	5%	4%
Large Offices (>30,000 sf)	17%	22%
Primary and Secondary School	8%	3%
Post High School Education	4%	3%
Total Market	**34%**	**32%**
Hospitals and Health Care	*4%*	*12%*

Source: CEC 2016, Attachment 12 PIER GFO 16-304

The highest priority for energy savings potential are large offices, both public and private, because they represent the largest floorspace and electricity use of any commercial sector type in California. Automated shades remain a premier product and California schools are more likely to respond to the lighting and RCx portions of the full retrofit package. In addition, hospitals and health care may offer good applications for the INTER solution set.

Project Products

To support the technology transfer (tech transfer) the team developed the following set of materials and industry resources to help advance the technologies to various audiences.

1. Getting Control of Comfort and Energy. This guide makes the case to owners and helps design teams and product representatives advocate to clients for the technologies.
2. INTER Guide for Installers and Design Teams. This defines project roles and considerations, and provides guidance for design, specification, and installation of these integrated retrofits with the INTER solution set.
3. Case Studies and Videos. These graphically rich materials provide stories of the owner's motivation, the benefits, and the actual outcomes at the two demonstration sites and on an additional shading product through a technology case study. Owner representatives are quoted in the case studies and recorded virtually in the videos as testimony for other owners and decision makers. Case studies: 3 | Videos: 2.
4. Reopening and Retrofit Blog, White Paper, and Owner Check List. NBI co-supported the development of a series of products to encourage upgrading existing buildings with integrated solutions as a path to reopening a better workspace.
5. Project Website and Materials. All materials and key reports on a dedicated NBI Leading in Los Angeles project website were shared through the market connection activities summarized below and detailed in the Technology Transfer section. In addition, NBI will be integrating products and results in n our ongoing efforts to improve buildings.

Market Connection Activities

Transferring a technology to the building industry relies on making market connections. The core strategies followed NBI's A-B-C approach:

NBI and its team conducted over 45 total tech transfer activities influencing an estimated 30,000 parties. In some cases, a single party can in turn influence a multitude of buildings so the connection count simply reflects points of contacts or subscribers. The types and number of tech transfer activities are summarized in Table 7 followed by a brief list organized by type.

Table 7: Tech Transfer Types and Counts

<table>
<tr><th>Strategy</th><th>Tech Transfer Type</th><th>Count</th><th># of Contacts</th></tr>
<tr><td rowspan="2">A. Industry Visibility</td><td>Publications</td><td>13</td><td rowspan="6">Estimate 30,000 +</td></tr>
<tr><td>Conferences and Webinars</td><td>14</td></tr>
<tr><td>B. Industry Connections</td><td>Industry Direct Connections</td><td>14</td></tr>
<tr><td rowspan="2">C. Program and Policies</td><td>Program Connections</td><td>4</td></tr>
<tr><td>Policy Connections</td><td>1</td></tr>
<tr><td></td><td>Total</td><td>46</td></tr>
</table>

Eight summary outcomes are spotlighted below that show how the exposure, momentum and industry engagement is already putting the INTER solution set into the hands and minds of practitioners who select technologies for building upgrades.

1. **California Public Buildings Staff Learn about LiLA.** NBI shared results to over 50 California state, city or county staff and contractors that influence their own buildings and establish programs and policies for their communities. Santa Ana has recently requested a bid for automated shades and lighting upgrades for other city facilities.
2. **CABA study on the impacts of automated shades.** The Continental Association of Building Automation (CABA) white paper *"Impacts of Automated Shading in Building Projects"* will include wireless PV powered controls due to TRC project team engagement in the study. This study is supported by major shade manufacturers who are now considering going toward wireless technologies to expand market share.
3. **Major publications spotlight LiLA.**
    - **Engineering Construction Management (ECM) magazine spotlights LLLC.** NBI's article on the benefits of Luminaire-level lighting controls (LLLC) and their impact at the CSUDH Welch Hall site was published in May 2021. LLLC is a key 'hook' technology to gain system integration.
    - **Forbes Magazine Article includes LiLA messaging about building retrofits.** A Forbes writer is drawing exclusively from the LiLA series of blogs on returning to the workspace with upgraded technologies that benefit energy, the climate, and occupants.
    - **Architectural Products (AP) Magazine showcases automated shades through NBI article.** In July 2020 AP, a go-to resource for designers, ran an NBI article (page 46) based on the LiLA project that showcased automated daylight directing shades.
    - **California practitioners see LiLA project through industry E-News.** LiLA results and resources are a part of newsletters and journals that go to tens of thousands of California building practitioners.
4. **Site Partners win awards and recognition due to LiLA project.**
    - **Santa Ana** was recognized with the annual national Smart Building Innovation Award for this retrofit project through the Smarter Building Alliance (SBT) and recognized in Yahoo Finance online news in March 2020.
    - **The CSUDH** lighting upgrade was recognized in the Statewide Best Practices for Sustainability, and as a model template in the DOE 2021 Lighting Innovation Campaign and news.
5. **Major Conferences include LiLA results.** LiLA results are a part of Light Show West 2019, DOE Better Buildings Summit 2020, ACEEE summer study 2020, California Universities Sustainability Conference 2020, BECC 2019, ETCC 2020, The California Energy Alliance 2021, NZ21 in LA (pending), NIBS Building Innovation Event (pending)**.**
6. **Results support national and California Building Commissioning Association (BCxA).** BCxA will use some of the RCx findings to support their work with the White House Council on Environmental Quality to expand information and resources for Cx program development as one of the critical steps in supporting decarbonization in new

construction and existing commercial facilities. The team will share findings with California BCxA members.

7. **Program Connections.** The team worked with SCE program staff to verify INTER solutions set eligibility under the new Normalized Metered Energy Consumption (NMEC) Commercial Solution within the commercial incentive program. PG&E is designing a similar incentive approach. Utility programs are noted and linked in all materials.
8. **Policy Recommendations.** The team policy report recommends T24 encourage automated shades and develop a calculation procedure to account for the impacts with minimal modelling inputs. Also, establish ACM calculation methods and procedures for all shades to make the process easier to include in the models (materials performance and thermal comfort criteria). An approach similar to ASHRAE 90.1 could be a model.

Benefits to California

Extrapolating from the measured energy savings described above, the INTER team estimates an average total energy savings of 29% in the retrofitted portions of a building. Based on that average savings, the team estimates a potential statewide savings 2,396 GWh, equating to 1,749 M pounds of CO2 savings, over 15 years, assuming a modest adoption rate of 2% of suitable building area per year.

Table 8 summarizes the estimated statewide energy savings impact of the INTER system retrofit package. Though the INTER package is designed primarily for office markets, the team estimates that the approach is also suitable for a portion of the state's School (60% of building area), University (50%), Medical Office, and Miscellaneous (30% each) sectors.

Table 8: Estimated Statewide Energy Savings Impact of INTER System Package

	Annual Existing Consumption (GWh)	Combined Measure Savings	Suitability of Bldg. Area (% of area)	Technical Potential Savings (GWh)	Annual Retrofit Adoption Rate	Total Adoption Potential Over 15 years (% of area)	Market Potential Energy Savings (GWh)	Consumer Savings (M $)	CO2 Savings (M Pounds)
Large Office Bldgs	18,902	29%	100%	5482	2%	26%	**1433**	**224**	**1046**
Small Office Bldgs	3,567	29%	100%	1034	2%	26%	**270**	**42**	**197**
School	2,683	29%	60%	467	2%	26%	**121**	**19**	**89**
University	2,149	29%	50%	312	2%	26%	**81**	**13**	**59**
Medical Office	10,172	29%	30%	885	2%	26%	**230**	**36**	**168**
Miscellaneous	11,505	29%	30%	1001	2%	26%	**260**	**41**	**190**
TOTAL	**48,978**			**9,180**			**2,396**	**375**	**1,749**

Conclusions

Despite unique challenges at each site, and the emerging issues of the new technology components, the demonstration project and research will help advance integrated technologies and lower energy use in existing buildings. The project met its primary research objectives, and its results and conclusions support the Commission and our industry's ongoing work to influence buildings to be better for people and the environment.

- **Existing buildings can take 20% off their energy use without a major renovation.** The INTER technologies do not require major disruption of occupied buildings. The technologies delivered strong lighting savings of 35-42%, HVAC savings of 6-29% and whole building savings of 15-26%.

- **LEDs, controls, LLLCs and retrofit kits lead the system.** The upgraded lighting system is delivering substantial energy savings due to overall lighting loads reductions from the mature LED technologies, controls with institutional tuning, and daylighting responsiveness. Control at the luminaire-level (LLLCs) offers optimum savings and highly valuable data at the occupant level that optimizes the HVAC system. Retrofit kits allow upgrades to the existing fixture at lower cost and faster implementation.
- **Shades are rarely adjusted manually**. Using weekly or more frequently as representative of 'active' shade management these findings indicate that the majority of survey respondents at both sites do not actively adjust shade positions. Just 28% at SACH and 40% at CSUDH actively manager their shade position. This follows similar studies further supporting the opportunity for automated shades to improve energy savings and indoor environmental comfort.
- **Project spurred new products.** A new PV powered panel will address site solar obstructions on windows and expand the opportunity for wireless, non-obtrusive, and more affordable technologies due to the absence of hard-wiring and associated labor costs. The new control system now provides operators real-time shade performance data and user preferences with increased machine learning.
- **HVAC tuning (RCx) remains a valuable efficiency strategy.** This project mirrored the numerous studies that show that for no capital costs a competent HVAC controls company can tune up the control sequence and deliver solid energy savings.
- **Integrated delivery of multiple technologies through a single vendor did not advance.** The project intended to demonstrate "Lighting as a Service (LaaS) that extended into the shade products due to the integration of the lighting sensors, shades and HVAC. While the lighting installation did occur through a turnkey model and remains a viable technology for LaaS and potential subscription approaches the shade technology is still too independent in production and complicated in installation.
- **M&V methods evolve due to lack of occupancy.** The COVID shelter in place forced some innovative thinking about how to measure the energy impacts of the new system. The INTER Team achieved calculations and results that are relevant to the project and provided a narrative of the actual impacts of the system changes on a building, even though we had only a brief period to compare the baseline and post-retrofit results.
- **Shade automation takes training.** The absence of effective and contemporary operational and interface training materials drove the project to develop a video for users and owners. The solution is supported by QR codes that are available to scan with a smart phone to gain local access to shade controls for transient occupants. This solution is a novel approach to broaden the availability of the shade controls to any user with appropriate permissions. Installer trainer guidance was also needed and created. Clear specifications in bid documents will help owners, contractors and installers.
- **Spotlight should be on the value to the 'three Os' – owners, operators and occupants.** Preliminary feedback from occupants and owners indicates an improvement in indoor environmental quality. The quality and functionality of the new shades is higher than those previously installed in the buildings, and the aesthetic

improvement is substantial. The roller shades allow view and connectivity with the outside even when closed. Operators gain energy and space use information from the integrated lighting controls. The project focused on benefits to these three Os in materials and outreach.

- **Performance specifications for shading systems are critical and mostly absent.** To advance this technology and assist the contractors in meeting the expectations of the design team and the owners there must be clear specifications. This will also help ensure that competitive bidding on some products is possible, which may reduce costs. Specifications include the shading materials and the shading controls system to define the expectations of the system after the project is complete. The technical "INTER Guide" for installers from this project helps address these barriers.
- **System integrators are a new, but highly valuable, role for commercial building retrofits.** A system integrator is responsible for ensuring that the various building systems (HVAC, lighting controls, shading controls at a minimum) are all smoothly communicating, and the commissioning of these systems is smooth and without gaps. In particular, the interface between the HAVC and lighting controls is a place where occupancy data for the HVAC zones needs to be collected by the lighting controls system and passed to the HVAC system.
- **Micro-PVs for technology power support building electrification and are an emerging and important building integration factor.** Self-powered technologies, like the project tested automated Illuminate™ shades, can help balance the growth in building electrification and support grid optimization.

1. Leading in Los Angeles Introduction

This final report summarizes the approach and findings from the California Energy Commission (Energy Commission) EPIC study named Leading in Los Angeles: Demonstrating scalable emerging energy efficient technologies for integrated façade, lighting, and HVAC control modifications. The set of technologies is called the Integrated Technologies for Energy-efficient Retrofits (INTER) solution set. The project launched in June 2017 and was a 4-year research study involving bench and lab testing, field demonstration, performance measurement and verification, and market assessment and connection efforts to move an integrated set of emerging commercial retrofit technologies into wider adoption.

The project prime is New Buildings Institute (NBI) and key team members are TRC Companies and Lawrence Berkeley National Laboratory (LBNL), and the technology partners Rollease Acmeda (Rollease), Daintree Lighting Controls, BeMotorized (BeMo), and additionally the installation contractors Smart Buildings Technologies (SBT) and Lumenomics. Collectively, this group of organizations comprises the INTER Team, which is used in this report to designate the various activities of the member organizations, and also when the pronoun "we" is used.

Research Goals

The technologies can be combined and customized to suit a variety of building types and spaces resulting in an estimated whole building energy reduction of more than 20%. Market attraction will be improved occupant control and comfort, reduced transaction costs, and potential energy savings from combined improvements. The project had two fundamental goals:

- Validate the commercial viability and scalability of INTER systems in existing commercial buildings.
- Accelerate market adoption of INTER system to address Los Angeles basin and statewide needs for energy and carbon reductions through deep energy efficiency retrofits.

INTER Package Technologies

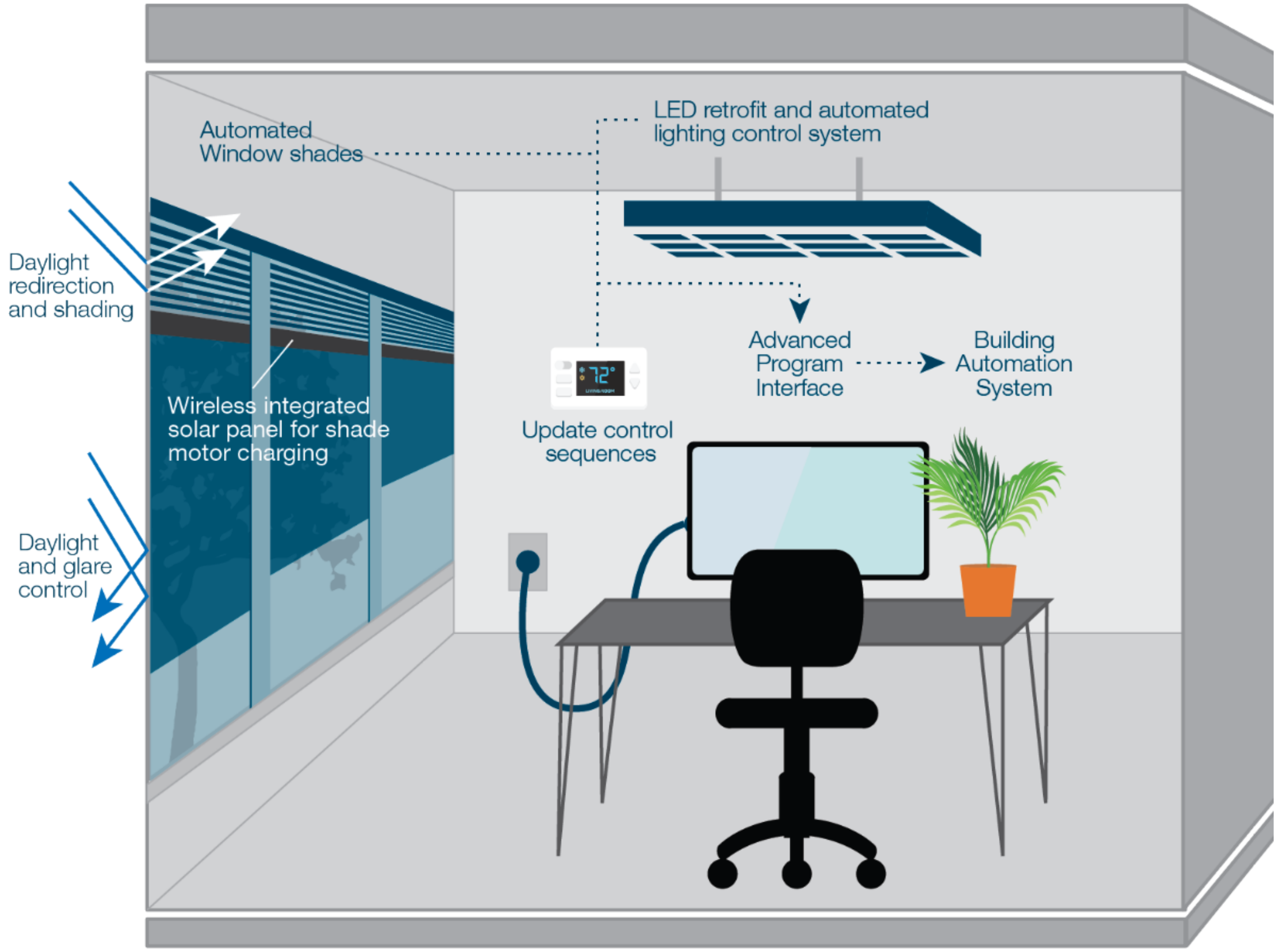
The INTER solution set combines an innovative set of pre-commercial and mature technologies targeting lighting, cooling and heating in commercial buildings. These end uses make up most of a building's energy use (approximately 70% for a typical office). The package includes automated wireless interior shades, LED lighting with networked lighting controls. In addition, the INTER Team demonstrated metering and measurement and verification (M&V) and adjusted controls through light HVAC retro-commissioning (RCx) to further the energy savings potential in the retrofit demonstrations. Each technology works together to create a cohesive package.

The technology package integrated three key efficiency components illustrated in Figure 2:

- Automated wireless interior shades with an upper daylight redirecting louver portion
- LED lighting with networked lighting controls (NLC)

- Light retro-commissioning (RCx) of the Heating Ventilation and Air-conditioning (HVAC) system

Figure 2: The INTER Technology Package



Source: New Buildings Institute and TRC Companies

Automated Shades

The Illuminate™ window shades from Rollease Acmeda combine shading and daylight harvesting with advanced controls. The Illuminate™ is a battery-powered motorized window shade system that optimizes for visual and thermal comfort and for energy savings. The power is provided from integrated photovoltaic (PV) panels that are sized depending on the size of the windows and solar availability. The innovative shading system consists of separated shade systems with the lower 'view' portion of the window employing a roller shade with a perforated fabric (typically about 3% perforations), and the upper 'daylighting' portion of the window using a louvered blind that can provide daylight to a space even when the view portion of the shade is closed to prevent glare. These two shade components can be independently controlled to address both daylight harvesting in conjunction with the lighting systems (upper blind system) and the preferences and needs of the occupants for daylight versus glare control and/or thermal control (lower roller shade system). For example, at times when a window is exposed to direct sunlight, the view portion of the shade can be closed to prevent glare and thermal discomfort for the occupant and the daylighting blind portion can be angled to reflect the direct sunlight toward the ceiling to maximize daylight harvesting through electric lighting controls while still preventing glare for the occupants. The shades can be controlled through multiple methods:

- With wall-mounted controller switches
- Via remote smart phone app
- An API to enable control through a BAS
- Pre-programmed automated schedules
- Through a sunlight sensor

The main controls approach for the field demonstration sites was to develop a blind/shade controls schema that would be employed based on solar time. This would address the main operations of the system and ensure that under normal sunny circumstances, the system is adjusting to maximize savings and minimize the potential for glare problems.

A user override through a phone app or a wall switch in the space would provide the opportunity to modify the shading system to permit more aggressive glare control (or less) and to enable shading settings to darken a space for presentations. Most of the time, these overrides should not be required. Any user overrides will revert to the standard program each night.

LED Lighting with Networked Lighting Controls

Both demonstration sites had existing lighting controls systems that were improved and updated to fully functional networked lighting control (NLC) systems. NLC systems typically combine a network of individually addressable luminaires and advanced sensors to provide control and monitoring capabilities for connected luminaires, adjust lighting levels, and maximize energy savings potential by dynamically balancing multiple data points (occupancy, daylighting, comfort, user preferences, etc.). In addition to the energy savings from the system itself, the NLC at the field demonstration sites collect data to measure the energy savings potential from daylighting delivered by the advanced shades systems described above.

Since the original development of this project proposal, the definition of an NLC has been standardized by the members of the DesignLights Consortium (DLC) for the purposes of supporting utility program implementation across the country. The relevant requirements of an NLC are as follows:

- Networking of luminaire controls across lighting zones/spaces
- Occupancy sensing
- Daylight harvesting
- Institutional dimming
- Individual addressability of luminaires
- Continuous dimming capability

This new definition means that the term “Advanced Lighting Control System (ALCS)” that has been used by the INTER Team in the proposal and in previous reports is now referred to by this newer and widely-accepted label and its clearly defined terms of performance per the DLC technical requirements[3].

The two demonstration sites had different existing lighting controls systems in the buildings and the INTER Team chose to maintain the existing lighting controls vendors in the respective buildings. Details of the lighting interventions at each site are described in more detail in the Technology Development section below. In both cases, the sophistication of the lighting controls was raised throughout the buildings. This enables more aggressive energy savings approaches in the spaces as well as better performance monitoring.

In the CSUDH Welch Hall building, the NLC is a category of lighting controls that are described as luminaire-level lighting controls (LLLC) and is a subset of the larger NLC category of lighting control systems. LLLC is characterized by the DLC as having several additional capabilities that can provide a higher resolution of lighting controls, leading to better adaptability and potentially higher energy savings opportunities. These additional requirements are:

- Must have an occupancy sensor and light level sensor installed on each luminaire.
- Sensors must be installed or embedded into the luminaire form (not be an add-on product).
- The luminaires must maintain control persistence even if the main network control system is disabled.

In the Santa Ana City Hall building, the lighting controls do not explicitly follow this set of requirements, and are therefore not explicitly LLLC, however the majority of the performance capability of the control system exists; just not in the pre-packaged form that the LLLC product category must take.

Most importantly, both systems have controls persistence if the main control computer is disconnected. This enables the lighting system to persist with energy savings actions that have been programmed into the system even if a communications fault or other failure brings about the reduction in the larger capabilities of the full NLC system.

HVAC Retro-commissioning

As part of the INTER system retrofits, the INTER Team worked with facility managers at the field demonstration sites to implement light-tough retro-commissioning to improve the efficiency of HVAC systems in coordination with the other installed technologies. Commissioning measures were limited to available and applicable programming adjustments, such as scheduling or sequencing refinements, tuning setpoints and setbacks, and implementing ASHRAE Guideline 36 standards for sequences of operations.

At the two demonstration sites, the recommended measures included in the retro-commissioning included:

- Optimum Start/Stop
- Demand Based Static Pressure Reset
- Demand Based Supply Air Temperature Reset

[3] For the full technical requirements of the NLC product category, please refer to the Design Lights Consortium website

- Rogue Zone Identification and Correction
- Cold Deck Temperature Resets
- Hot Deck Temperature Resets
- AC Hydronic Valves Lockout
- Hot Deck Heating Lockout
- HHW Booster pump and steam valve interlock
- CHW Booster pump and CHW valve interlock
- Zone Box Sequence of Operations Optimization
- Reduce Minimum Airflow
- HD and CD Damper Lockouts
- Widen Zone Deadband
- AHU scheduling with Optimum Start/Stop
- Economizer Optimization
- Implement Zone Grouping and Zone Setback

2. Project Approach

Demonstration Sites and Selection Process

A key activity for the field demonstrations was site selection. During the proposal phase, the INTER Team partnered with the City of Santa Ana and the Los Angeles County Metropolitan Transportation Authority (LA Metro) to identify potential sites for field demonstrations of the INTER technologies. Both agencies agreed to support the project and participate in the field demonstrations with retrofits at one or more of their buildings.

Once the project commenced, the INTER Team began in depth evaluation of the potential sites. This evaluation considered multiple layers of priorities. First and foremost, demonstration sites needed to be a good fit for the INTER technologies, represent common existing building performance and baseline technologies seen in the state, and ideally include use cases that have broad market applicability. To address these broader goals, we focused on opportunities for whole-building retrofits with primarily office uses - the top market for the shading technology.

The office building category (large office and small office) represents a substantial proportion of the existing commercial building square footage in the California IOU territory area, estimated at about 22% of the total nonresidential building stock, and approximately 3,226 million square feet total. In addition to this, there are several other building types that are likely good candidates for this retrofit approach as well. Based on professional experience, the INTER Team estimates approximately 60% of school building, 50% of university, 30% of hospital, and 30% of miscellaneous building square footage are likely good candidates for the INTER approach for retrofit. These four building types combine to approximately 36% of the total commercial building stock and 5,238 million square feet.

In addition, the terms of the grant established further parameters for the INTER Team to consider. Field demonstration sites must meet all the following requirements:

- Government Buildings and Facilities
- A total of at least 250,000 square feet across multiple sites
- Electrical service from SCE or SDG&E
- Location in Los Angeles or Orange County
- Conditioned buildings
- CalEnviroScreen score of at least 75%

Based on the criteria and considerations outlined above, the INTER Team developed a set of ideal demonstration site characteristics to guide the site selection process and ensure a successful demonstration. These ideal characteristics are as follows:

- Full building retrofit preferred over doing multiple partial buildings.
- Typical office occupancy without unique loads – consistent occupancy and ideally owner-occupied.
- Typical, highly glazed façade with direct sunlight (no existing shading/overhang).

- Lighting baseline conditions and technologies that reflect a large part of the existing buildings marketplace such as fluorescents, T12s or T8s and occupancy and/or daylight controls. These will provide the best opportunity to measure impacts with widely transferable benefits (energy, comfort, etc.) and make a "good story".
- Modern HVAC control system (highly preferred) in order to retro-commission the controls.
- No construction or occupancy changes planned for project term.
- Enthusiastic owner, occupants.
- Multiple sites, ideally with different site owners.

Once the INTER Team had established the various criteria for field demonstration sites, we evaluated a variety of sites proposed by both the City of Santa Ana and LA Metro. The City of Santa Ana had initially proposed four sites, and LA Metro had proposed two. In addition to those initially proposed sites, we worked with both entities to identify additional potential sites. Despite a variety of potential facilities to choose from, it quickly became clear that none of the initially proposed sites were ideal for the field demonstration. Due to the challenges of reconciling the grant requirements, procurement processes and constraints, and the field demonstration timeline, LA Metro was unable to participate in the demonstration project.

After evaluating various City facilities, the INTER Team and the City of Santa Ana selected the Santa Ana City Hall building as one of the field demonstration sites. The City Hall building was not one of the potential sites initially identified for the project, but in discussions with the city it became clear that the INTER technologies would be well suited to improving energy efficiency given the existing conditions.

To address the loss of LA Metro, the INTER Team leveraged existing relationships at California State University Dominguez Hills (CSUDH) to bring a second owner entity into the project. The CSUDH Facilities Manager is very enthusiastic about new building and controls technologies and energy efficiency and has been an excellent partner for the field demonstration. Working with CSUDH, we selected Welch Hall, a primarily administrative building with year-round occupancy, as the second demonstration site.

The two selected sites are outlined in Table 9 and were formally approved by the California Energy Commission CAM for participation in the study.

Table 9: Selected Field Demonstration Sites

Building	Owner	Location	Year Built	Building Size	Retrofitted Area
Santa Ana City Hall	City of Santa Ana	20 Civic Center Plaza Santa Ana, CA	1970	127,000 sq. ft. 8 floors (plus basement)	88,000 sq. ft.
Welch Hall	California State University Dominguez Hills	1000 E Victoria St Carson, CA	2001	183,000 sq. ft. 4 floors	131,000 sq. ft.

Santa Ana City Hall

The Santa Ana City Hall (SACH) building was built in 1970, consisting of an eight-story office tower, plus a basement, as well as City Council chambers. Further office space was added to the complex in an addition to the area northeast of the original tower. Only the eight-story office tower is included in the field demonstration due to the specialized nature of the Council Chambers, and the different architectural characteristics of the newer addition that are less conducive to the full range of INTER technologies.

The SACH office tower has relatively narrow floorplates on the fourth through eighth floors, with extensive windows facing north and south. As a result, almost all spaces on these upper floors have access to daylight. The first, second, and third floors have larger floorplates, and while the perimeter offices have extensive windows and access to daylight, there are also inner core office spaces that have no daylight access. Figure 3 provides images of SACH exterior.

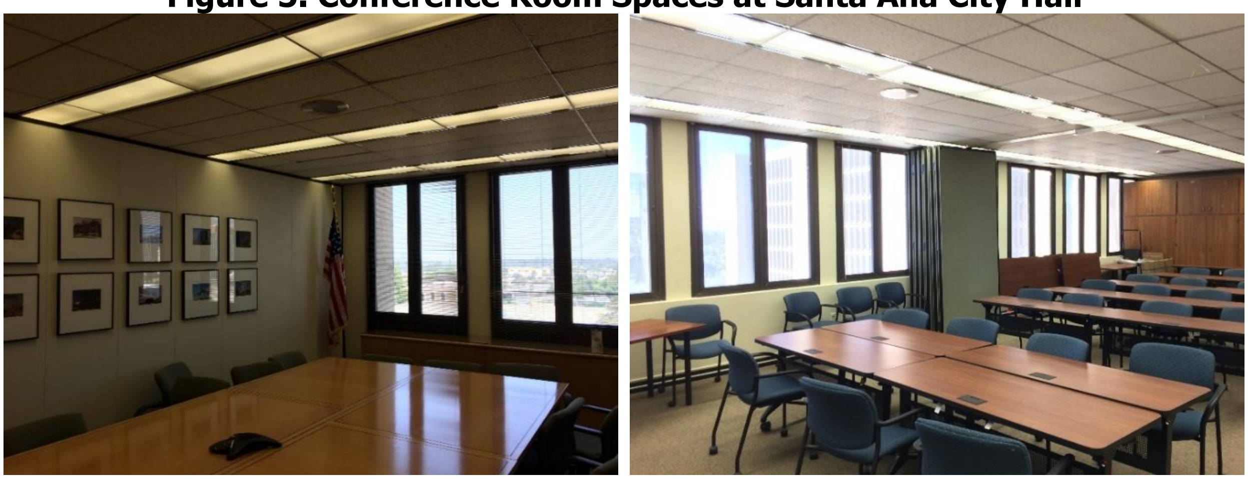
Figure 3: Exterior View of Santa Ana City Hall Office Tower

The office tower consists primarily of private offices and small shared open office spaces as seen in Figure 4 as well as conference rooms, shown in Figure 5. However, these space types occur in a wide variety of sizes and configurations throughout the building, as reflected in the example images below. The building also employs an unusual ceiling grid configuration. Instead of the typical 2' x 4' grid found in the vast majority of office buildings, SACH has an 18" x 36" grid. Lighting fixtures are configured in continuous recessed strips, typically spaced six feet apart on center. Because the existing lighting system used standard 4' T8 lamps that do not align with the 18"x36" ceiling grid, there were frequent cases where lamps crossed walls, or where portions of a lamp was hidden behind a solid ceiling tile. As a result, most spaces did not have local manual lighting controls except for some conference rooms.

On the typical tower floors, there were only two control points for all the lighting on each floor, one at each end of the floor. While this unusual configuration by today's standards posed some challenges for the retrofit, it also presented significant opportunities for lighting energy savings and does reflect the practice at the time of construction which may be present in other older office buildings.

Figure 4: Private Office (left) and Open Office (right) Spaces at Santa Ana City Hall

Figure 5. Conference Room Spaces at Santa Ana City Hall



Window configurations and conditions are somewhat different on the second and third floor, where windows are configured in horizontal bands on the west, south, and east sides, as illustrated below in Figure 6; and a decorative architectural frieze shades some second-floor windows from most direct sunlight.

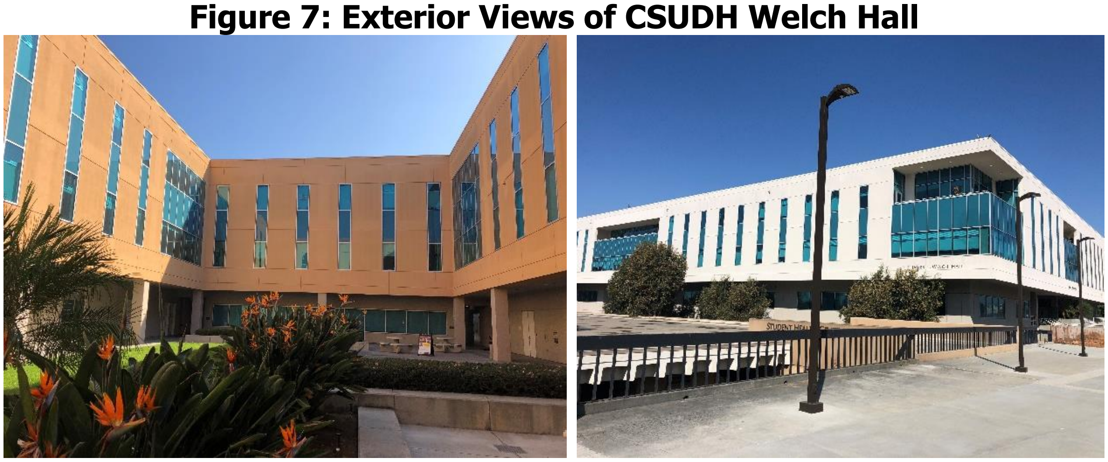
Figure 6: SACH 2nd Floor Private Office (left), and 3rd Floor Open Office (right)

At the outset of the study, the second floor of SACH was unoccupied, but due to flooding on the basement level staff that had been located in the basement have been permanently relocated to the second floor.

CSUDH Welch Hall

Welch Hall was built in 2001 as primarily an administrative office building for the University. Welch Hall is a large four-story rectangular building of 183,000 square feet. The first floor, partially below grade, houses some large windowless classroom spaces, as well as some office spaces at the perimeter. The second through fourth floors contain offices, conference rooms, and related support spaces. A large interior courtyard space on the second through fourth floors provides additional daylight access for spaces on those floors as seen in Figure 7.

Figure 7: Exterior Views of CSUDH Welch Hall



The building contains a variety of glazing conditions, with both punched windows as well as horizontal bands of windows, and has exposures in all four cardinal directions, providing a variety of conditions to test the automated shades and daylight harvesting aspects of the INTER technologies. For example, some spaces may only have a single narrow window, while some corner spaces have two full walls of glass, as shown in the images in Figure 8 below. Like SACH, the interior is primarily a mix of private office, open office, and conference room spaces. Existing lighting in the building was primarily comprised of lensed 2’ x 4’ T8 troffer fixtures.

Figure 8: Variety of Pre-existing Window Conditions at CSUDH Welch Hall

Final Technology Installations

The sites offered varied configurations as described above for the research technologies. Lighting retrofit upgrades occurred to 4,402 existing ceiling-based fixtures utilizing the Enlighted luminaire-level lighting controls at CSUDH and Daintree controls at Santa Ana. The final shade installation resulted in 953 new shades installed with 32% of these (306) being the Rollease Acmeda Illuminate product and 36% of all shades automated. Retro-commissioning was completed at both sites with CSUDH having enhanced HVAC control modifications by the building manager. The final technology installation count by site is show in Table 10.

Table 10: Final Technology Installation Count by Site

Technologies	Santa Ana	CSU DH	Totals	Ratio of shades
Advanced Light Fixtures	2,413	1,989	4,402	n/a
Illuminate Shades[1]	142	164	306	32%
Automate Shades	2	37	39	4%
Manual Shades	337	271	608	64%
Total Shades	481	472	953	100%
RCx	Yes	Yes +[2]		

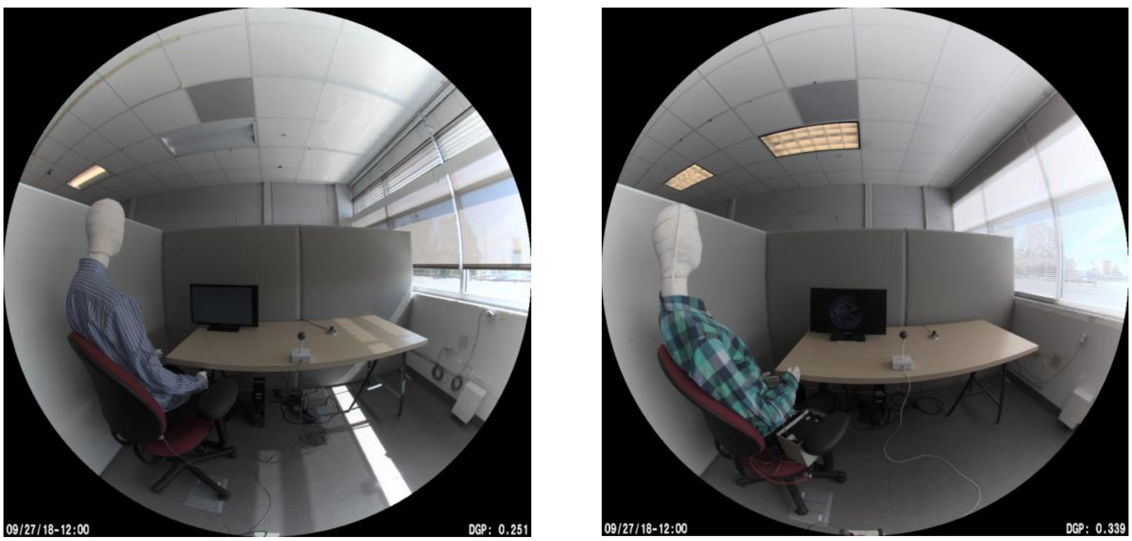
[1] *With daylight redirecting upper louvers* [2] *Additional control mods by Building Manager*

Lab Testing Methodology

The two main objectives of the FLEXLAB testing were to 1) evaluate the energy performance of the INTER shading and daylighting control system (determine energy savings compared to 'typical' existing baseline as well as code baseline; disaggregate lighting and HVAC energy savings), and 2) evaluate the visual and thermal comfort performance of the INTER shading and daylighting control system. The INTER system was tested over three seasons (summer, fall, winter) in parallel to two alternating baseline configurations:

1. Existing building baseline with manually operated venetian blinds and fluorescent lighting with no daylight-based dimming.
2. California Title 24 code-compliant baseline with manually operated venetian blinds and lower-wattage fluorescent lighting with zonal daylight-based dimming.

Figure 9. Side-by-side view of baseline (right) and retrofit test configurations (left)



In addition, the testing was meant to provide feedback and lessons learned on the installation, commissioning, and operation of the INTER shading and daylighting control system, especially aspects that affect operations and maintenance, savings persistence, or user acceptance. The side-by-side photographs above from the high dynamic range (HDR) glare sensors shows the basic configuration of the baseline (right) and retrofit (left) cells; visible are the shading systems, electric lights (note daylight dimming in left photo of retrofit), cubicle layout, and light and mean radiant temperature sensors (on the desk).

Table 11 provides the details for the Baseline and the Retrofit test cell configuration and include an existing building and a Title 24 code-compliant baseline with the glazing area as a 'Full-window' and with the introduction of physical cover such as cardboard to simulate a "Mid-window" size area.

Table 11. Test Cell Configurations

<table>
<tr><th rowspan="2">Description (Abbr. in column to the left)</th><th>Both Cells</th><th colspan="3">Baseline Cell</th><th colspan="3">Retrofit Cell</th></tr>
<tr><th>Window-to-Wall Ratio</th><th>Lighting System</th><th>Lighting Dimming Controls</th><th>Shading System</th><th>Lighting System</th><th>Lighting Dimming Controls</th><th>Shading System*</th></tr>
<tr><td>Full-window, existing building baseline</td><td>~ 0.50</td><td rowspan="2">Fluorescent:
3-lamp T8 troffers</td><td rowspan="2">No daylight-based dimming</td><td rowspan="4">Manually operated venetian blinds</td><td rowspan="4">LED troffers</td><td rowspan="4">Fixture- level daylight dimming</td><td rowspan="4">Automated roller-shades and daylight redirecting louvers</td></tr>
<tr><td>Mid-window, existing building baseline</td><td>~ 0.40</td></tr>
<tr><td>Full-window, Title 24 code-compliant baseline</td><td>~ 0.50</td><td rowspan="2">Fluorescent:
2-lamp T5 troffers</td><td rowspan="2">Stepped dimming near windows</td></tr>
<tr><td>Mid-window, Title 24 code-compliant baseline</td><td>~ 0.40</td></tr>
</table>

* At the time of this lab evaluation, automated solar tracking controls were not commercially available, but scheduled operation of the shades and blinds via smartphone app and Wi-Fi hub was.

Site Measurement and Verification Analysis Plan

The original M&V plan for the field demonstration sites addressed the following objectives:

1. Determine and compare annual electricity energy savings of the INTER system using whole building metering vs. end-use metering. The savings would be determined using protocols acceptable to IOU incentive programs.
2. Analyze the relative savings contribution of each component of the INTER system.

For objective 1, the intent was to assess and compare whole building and end-use metering-based approaches in terms of their accuracy vs. metering cost and effort. This information would then be used to develop a streamlined M&V methodology and specification for INTER that could be applied broadly beyond the demo sites themselves.

Objective 2 uses conventional M&V methods to parse out the component-level savings of INTER. This analysis is primarily for deeper diagnostic understanding of the savings profile of individual components, which in turn could also inform savings estimates for buildings other than the demonstration sites.

A key intended feature of the INTER system is the use of "built-in" streamlined M&V using M&V 2.0 approaches. M&V 2.0 generally refers to the use of automated analytics in combination with higher granularity data to quantify project energy savings . The main benefits and distinguishing characteristics of M&V 2.0 compared to conventional utility program M&V are: 1) early and more continuous evaluation of savings, which allows for corrective measures if savings are not as expected; 2) the time-dependent valuation of savings; and 3) potential reduction in labor and cost for M&V.

Integrated systems such as INTER are generally well-suited to whole building M&V because they affect multiple systems with interactive effects. Furthermore, the expected magnitude of the savings (25-32%) is well above the minimum threshold need to overcome "signal-to-noise" issues associated with savings based on whole building meter data.

The original M&V plan intended three different M&V approaches for saving analysis:

- Whole building pre- and post-retrofit metering normalized to selected independent variables such as outdoor air temperature or day of the week.
- Spatial (e.g., by floor or daylit zone, etc.) and/or end-use (lighting, HVAC, etc.) metering, using a combination of submetering and system data, with independent variables customized to space or end use characteristics.
- Component level M&V, using a combination of end use metering, system data, and potentially some temporary metering.

Plan Modifications due to COVID-19

The post-retrofit monitoring and analysis period for the full set of INTER systems technologies was planned for July 2020 through March 2021. However, due to the COVID-19 pandemic, it was unclear if and when the demonstration sites will return to normal occupancy, and as of this writing, still has not returned to normal occupancy.

Based on the impacts outlined above, the INTER Team developed a set of M&V strategies to determine a set of market-facing outcomes that will best demonstrate the research intent of the project, given the limitations at the site for occupants, and to provide findings that can inform other work as part of this project.

Planned tests for the demonstration sites are outlined as follows based on the market-facing outcomes desired. Unless otherwise noted, approaches will be similar for both sites:

- Whole building savings of the system under normal occupancy: This was as planned using M&V 2.0 strategies, with data collected prior to the reduction in occupancy due to pandemic shelter-in-place orders.
- How much does the building energy use turn down with low to no occupancy when systems are "on"? The intent was to compare whole building, HVAC, lighting, and plug loads pre- and post-shelter-in-place.
- The story of a retrofit and a pandemic: plotting actual energy use over time from pre-retrofit through current, annotating key events in both the retrofit process and the shelter in place.

- How effectively are end use energy changes reflected in whole building energy use? What is the signal to noise ratio? The intent was to compare the impact of calculating savings using whole building meter data vs. end use data.
- How much additional lighting energy reduction does daylight redirection provide? The intent was to identify rooms with similar orientation, layout, and size. Some rooms would be set up as a reference case without the use of automated daylight redirection, and then compared to other rooms that have nominal operation of the louvers. The comparison would focus on lighting energy use as well as operative temperature.

In summary, though the change in occupancy eliminates the ability to obtain equivalent metering of actual energy use during the pandemic, the INTER Team's revised M&V plan provide an alternative strategy for analysis of the technology performance in the current conditions.

Pre-demonstration Indoor Environmental Quality Surveys

As part of the initial analysis plan, the INTER Team planned to conduct pre- and post-retrofit occupant surveys to gauge indoor environmental quality (IEQ) effects from the INTER system retrofits. Due to a lack of occupancy during the pandemic SIP, the team was unable to conduct post-retrofit surveys at the demonstration sites. Results of the pre-retrofit survey are presented here to characterize existing IEQ conditions and occupant satisfaction prior to the retrofits.

Pre-retrofit general IEQ surveys were conducted at SACH from January 28, 2019 to February 19, 2019, and at Welch Hall from February 15, 2019 to March 5, 2019. At SACH, 108 participants responded to at least some of the questions, with an estimated 93 completing the full survey. At Welch Hall, 192 participants responded to at least some of the questions, with an estimated 157 completing the full survey. The surveys were focused generally on satisfaction with the building and occupants' workspaces overall, as well as thermal comfort, lighting, and views. Initial results from these surveys are outlined below.

Table 12 below shows the average satisfaction result for both demonstration sites compared to the CBE Survey Database average for the four main categories: building overall, workplace, thermal comfort, and lighting. Satisfaction with views is not shown because the view questions were custom additions for this study, and therefore do not have a benchmark in the CBE Survey Database. Satisfaction is rated on a 7-point Likert scale, where 1 is "very dissatisfied", 4 is "neutral", and 7 is "very satisfied".

Table 12: Average Pre-Retrofit IEQ Survey Satisfaction Results for Demo Sites

	Santa Ana City Hall	Welch Hall	CBE Database Benchmark
General Satisfaction – Building	4.11	4.72	5.11
General Satisfaction – Workplace	4.82	5.03	5.08
Thermal Comfort	3.85	3.81	4.09
Lighting	4.86	4.96	5.23

Average satisfaction for both demonstration sites was slightly lower than the CBE Benchmark in all categories. Satisfaction at Welch Hall was slightly higher than SACH in all categories except thermal comfort where they were roughly equivalent. This may be due in part to the fact that Welch Hall is a newer building.

As illustrated in Table 13 below, at Santa Ana City Hall, 21 of 52 respondents (40%) reported never adjusting the shades in their workplace, and a further 17 (33%) said they adjust their shades less than once a month. Only two (4%) said they adjust the shades multiple times per day, and five (10%) reported they adjust the shades once per day. At Welch Hall, 27 of 88 respondents (31%) reported never adjusting the shades in their workspace, and a further 21 (24%) said they adjust their shades less than once a month. Only eight (9%) said they adjust the shades multiple times per day, and 14 (16%) reported they adjust the shades once per day. (Note that percentages may not add to 100% due to rounding.)

Using weekly or more frequently as representative of 'active' shade management these findings indicate that the majority of survey respondents at both sites do not actively adjust shade positions. At Santa Ana City Hall only 28% of the survey respondents actively managed the shades whereas at Welch Hall 40% of respondents indicated active management through weekly, daily or multiple times daily adjustments. Part of this difference may be explained by the different occupancy patterns in the two buildings, where Welch Hall has a higher proportion of private offices where occupants may be more likely to adjust the shades to their preferences, whereas Santa Ana City Hall has a higher proportion of shared office spaces. In addition, Welch Hall has east- and west-facing aspects where occupants may be more likely to actively adjust their shades to prevent glare and heat gain from low angle direct sunlight. In contrast, Santa Ana City Hall has almost exclusively north- and south-facing windows, where occupants may be more likely to keep their shades always closed (south-facing) or always open (north-facing).

This follows similar studies[4] further supporting the opportunity for automated shades to improve energy savings and indoor environmental comfort.

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[4] 2017 University of Oregon window blinds research wins global award

Table 13: Frequency of Pre-Retrofit Blind or Shade Adjustment

Q: You indicated you have access to control the window blinds or shades. How often do you open and close your blind/shade?	Santa Ana City Hall	CSUDH Welch Hall
Multiple times a day (more than once a day)	2 (4%)	8 (9%)
Daily (typically every day)	5 (10%)	14 (16%)
Weekly (1-3 times a week)	2 (4%)	13 (15%)
Monthly (1-3 times a month)	5 (10%)	5 (6%)
Less than once a month	17 (33%)	21 (24%)
Never	21 (40%)	27 (31%)
Total	**52**	**88**

As Table 14 below shows, at Santa Ana City Hall, 68 of 98 respondents (69%) were at least somewhat satisfied with their access to window views (12 somewhat satisfied (12%), 25 satisfied (26%), 31 very satisfied (32%)), 18 (18%) were neither satisfied nor dissatisfied, and a total of 14 (14%) were dissatisfied (8 somewhat dissatisfied (8%), 2 dissatisfied (2%), 2 very dissatisfied (2%)). At Welch Hall, 89 of 164 (54%) were at least somewhat satisfied with their access to window views (6 somewhat satisfied (4%), 30 satisfied (18%), 53 very satisfied (32%)), 35 (21%) were neither satisfied nor dissatisfied, and a total of 40 (24%) were dissatisfied (13 somewhat dissatisfied (8%), 7 dissatisfied (4%), 20 very dissatisfied (12%)).

Higher satisfaction rates with access to views at Santa Ana City Hall are likely the result of narrower floorplates and higher window-to-wall ratios, allowing more occupants access to at least some window view.

Table 14: Pre-Retrofit Satisfaction with Access to Window Views

Q: How satisfied are you with your access to a window view?	Santa Ana City Hall	CSUDH Welch Hall
Very Satisfied	31 (32%)	53 (32%)
Satisfied	25 (26%)	30 (18%)
Somewhat Satisfied	12 (12%)	6 (4%)
Neither Satisfied nor Dissatisfied	18 (18%)	35 (21%)
Somewhat Dissatisfied	8 (8%)	13 (8%)

Q: How satisfied are you with your access to a window view?	Santa Ana City Hall	CSUDH Welch Hall
Dissatisfied	2 (2%)	7 (4%)
Very Dissatisfied	2 (2%)	20 (12%)
Total	**98**	**164**

3. Delivery Model and Technology Assessment

This section summarizes the high-level findings and conclusions of core premises from this research project, namely: lighting as a service and turnkey delivery can support the widespread adoption of retrofit packages, and pre-commercial technologies have significant potential to advance in technology readiness to become widely and rapidly deployable.

Lighting as a Service (LaaS)

At the outset of this research project, the intent was to evaluate "turnkey" services that combined automated shades and the LED and NLC retrofits under a single delivery model. The project initially planned to pursue a "lighting as a service" (LaaS) delivery model for the lighting retrofit, in which a vendor provides retrofit equipment, installation, and ongoing maintenance on a subscription basis. This approach can be an option for many simple lighting delivery systems, but in the circumstances that occurred with the two demonstration buildings, this solution was not a viable approach for the following reasons:

- At CSUDH Welch Hall, the facilities team was very actively engaged in this project (and all other buildings on the campus), and they did not have a way of accommodating the LaaS approach within their current work and service mandates.
- At Santa Ana City Hall, the lighting system proved to be unique in some design details and the facilities manager is accomplished at maintaining the existing system, but an external company would not likely be so successful.

The LaaS approach was deemed not viable and abandoned at both of these project sites but remains a viable option for other projects seeking lighting retrofits.

Turnkey Delivery

Although site-specific conditions presented challenges for both lighting retrofits, the planning and implementation of those retrofits at each site largely conformed to the "turnkey" expectation at the technology level with a primary vendor developing lighting and controls solutions and coordinating the implementation.

The shades system, however, required the coordination of multiple separate services and vendors for installation, programming, and commissioning. Some further coordination was also required at each site to integrate HVAC retro-commissioning with lighting controls signals.

Overall, lighting remains a highly viable technology for turnkey installation and a services model. The integration of multiple products and controls under a single vendor with expertise across product lines, however, was not an outcome adopted through the participants in this project. Although entities like Energy Service Companies (ESCOs) do manage multi-technology retrofits there remains a need and value for a 'systems integrator' model as a standard for commercial retrofits.

A Sum of the Parts: Findings and Recommendations by Technology

The INTER system components are intended to operate in a semi-coordinated manner. Due to this, there are barriers to implementation that can be expected to occur because the system is a step beyond the typical energy efficiency measures that are commonly implemented in existing office buildings. The INTER system's shade technology is relatively new for any implementation and therefore requires contractor awareness and training.

As the shading technologies advance, the deployment of integrated systems and a "plug and play" solution becomes increasingly viable. The shading and lighting systems can operate independently, with each responding to user inputs and lighting conditions. The primary pre-commercial technology in this project was the automated shade which underwent significant development in response to this project.

Pre-Commercial Automated Shades

The novel automated shades are simple in concept – a combination of roller shades and horizontal blinds, both of which are mature technologies. The controllability of these two individual sections and the self-powering via PV panel of the assembly is where the pre-commercial innovation lies.

Shade Controls

The shade manufacturer, Rollease Acmeda, did not have native controls for the automated shades as expected for this project. The project team therefore sub-contracted BeMotorized who provided 3rd party controls for the shades. BeMotorized offered substantial development time as in-kind match funding to develop a controls algorithm that could offer remote operation of the shades. The BeMotorized system now offers cloud-based remote control of roller shade positioning via web browser, smartphone app, or physical buttons located near the shades. Shades may be grouped together to control zones or rooms simultaneously.

BeMotorized offers zonal programming, scheduling, maintenance, fault detection and diagnostics, and business intelligence data as part of a subscription model. These advanced, automated controls can be integrated with other building systems to optimize shade positioning based on user preferences, scheduling, and other sensors in the building (occupancy or lighting). The shade automated allows building owners and occupants to optimize their system for daylight harvesting, solar heat gain, and privacy without reliance on occupants to regularly adjust shade positioning.

Powering Wireless Shade Control Infrastructure

The shade controls system utilizes a wireless connection to the shade units and a gateway device that must be within approximately 100 feet of the shades. This gateway is plugged into both ethernet and a power source.

Producing a suitable power source for the gateways is likely a substantial challenge in a retrofit situation. First, the gateways are best placed in the ceiling plenum to keep them out of sight, but there are specific codes that regulate the power that can be put in a ceiling plenum. In most places, a power receptacle cannot be used in a plenum for a permanent installation.

For this project, we adapted the system to provide power over ethernet (POE). Given that the gateways were not designed to be powered this way, it was a more complex and expensive way to achieve a power source for the relatively small load required for the gateways.

The easiest way to manage this in the gateways is to change the product to make two variants available; one that is able to screw onto a simplex or duplex 120V or 277V electrical box and hard wire through the base into the box. The second is to make the unit directly compatible with POE sources without the need to split out the power and into the gateway -- simply plug the POE cable in and the gateway should sense the voltage and accommodate it. This recommendation was shared with the manufacturer.

Solar PV and Power Availability

The solar charging system employed in this project is an enabling technology for the shades, but it is not without its own set of complications. The benefits of the solar panels in this project are that automated shades could be installed in a more cost-effective manner without the need for hard-wired power to be brought to each shade location for operation. The cost of that wiring and necessary disruption to the space have been primary reasons that automated shades have not been viable in retrofit situations up to this point. The solar charger and battery-operated shades address this shortcoming in a way that makes a compelling impact on the total installed cost of these automatic shade systems.

However, the solar panels have a limited range of operating conditions, and there are likely to be many building applications that will be determined as unsuitable for the application of this approach. Buildings with strongly tinted windows are unlikely to be good candidates for a viable solar delivery system, even if the tint does not obviate the need for glare control in the form of shades or blinds. A strong window tint makes solar panels less viable due to the lower delivered illuminance on the panel. This will be compounded by positional shading or overhangs on the building exterior façade and may result in a circumstance where the solar panel is unable to sufficiently charge the batteries to keep the motors running.

As a result of this project, the manufacturer of the shades (Rollease Acmeda) is developing a fourth generation PV panel that will have improved performance at lower illuminance levels, allowing for a broader range of applications, including northern-facing and obstructed windows. Although improvements in PV panels will greatly expand the applicability of this solution, not every building will be a good candidate for PV-powered shading systems depending on their solar availability and glazing.

Integrated Batteries

The battery for the motor is incorporated into the motor spindle (inside the roll of shade material, or in the transom segment for the upper louver sections). This may be the weak point for the system, assuming most other items have a long service life, because the batteries are a known maintenance item. Since there is a solar trickle charger, the batteries should last a very long time before they are unable to hold sufficient charge, but when that time occurs, there will be a need to replace the motors entirely since the batteries are incorporated into the motor assembly.

Since solar panels also have a service life and the efficiency of solar panels is slowly improving, replacing a solar panel/charger and battery assembly might be a more logical approach, especially since the solar panels are mounted externally to the shade housing and the replacement could be as simple as disconnecting the panel electrically and removing it from the housing to then install a new one. An improved design might be to consider a separate battery that is either incorporated into the solar panel or is a complete stand-alone item for a more straightforward replacement. This recommendation was shared with the manufacturer.

Research Site Modifications to Address PV-Panel Issues

The originally installed PV-panels failed to provide adequate charge to the batteries to operate the upper louvers and lower shades in locations with sufficient solar impedance. This occurred almost universally on north facing windows and regularly on windows with overhangs or other solar obstructions as noted above. This failure, when observed during final shade commissioning at both sites, caused a major project team and manufacturer negotiation resulting in an extensive second set of new PV panels and shade reconfigurations.

The product and shade modifications provide fully functional window treatments for the research site participants while maintaining the intended energy and comfort attributes of the project. A summary of site modifications and notes on impacts are as follows:

- Replaced PV panels with the next generation of PV Panel (Gen 3) at 345 windows with strong solar access. Gen 4 is in design and testing to address the shortcomings.
- Upper blinds on all Illuminate products were put into a fixed position that balances daylight and glare. In the lab testing varying the louver position was found to have minimal advantage to increase energy savings.
- Disables the upper louver motor from the PV panel to reduce battery energy draw.
- All solar impeded windows were changed to manual shades.
- Negligible energy impact of these changes at the sites due to maintaining the upper louvers in a fixed positions to continue to interact with the lighting sensors.

As shown in Table 15 in the original design Santa Ana had 55% of the installed shades automated and CSUDH had 97% automated shades. After the reconfiguration to address the PV panel issues, they had 30% and 43% respectively. This was still a substantive upgrade from their pre-retrofit of fully manual shades or blinds. Site owners, although desirous of the more extensive set of fully automated shades, understood and accepted the revisions.

Table 15: Original and Final Proportion Automated Shades by Site

% Automated Shades	Santa Ana	CSU DH	Avg. Both Sites
Original install	55%	97%	76%
Final install	30%	43%	36%

Summary of Technology Readiness Impacts

The Technology Readiness Level (TRL) is an assessment of the development stage of a product relative to full market readiness, with the intent to guide organizations in the investment into a product or technology and ultimately advance the product toward market readiness.[5]

The TRL ranges from TRL-01, which is a concept that hasn't been explored other than in the theoretical realm, to lab testing (TRL-03 to TRL-05), through initial engineering tests (TRL-05 to TLR-06), initial technology demonstration (TRL-06) and full-scale demonstrations (TRL-07 to TRL-08), and finally initial implementation and demonstration of final production samples (TRL-09).

As expected, the LED lighting, lighting control devices, and the HVAC controls are of TRL-09 or above (defined as having extensive implementation or in widespread commercial use). As a result of this research project, the shading hardware (specifically the PV panel) and its controls substantially advanced in technology readiness. Both the PV panels and shade controls TRL were overstated by Rollease Acmeda at the outset of the project.

As shown in Table 16, the TRL for the PV panel that charges the shade motor is now at TRL-06 with the anticipation of the Generation 4 solar panels that will offer better charging potential in north-facing and obstructed windows. At the start of the project, the Generation 2 panels were underperforming in terms of charging potential and further generations of panels were developed with extensive feedback from this project. The shading controls were fully adapted to this shading product as a result of this research as the manufacturer did not have controls in place for these automated shades. The control system from BeMo is now firmly in the TRL-07 to TRL-08 range.

Table 16: Technology Readiness Level (TRL) Changes Supported by this Research

	Start of Project TRL	Current TRL
LED Lighting	09	09
Networked Lighting Controls and Luminaire Level Lighting Controls	09	09
Automated Shade Controls	05-06	07-08
Shade Integrated PV Panel	04	06

[5] The TRL approach used for this assessment is based on the DOE guidelines established by LBNL in the document Technology Readiness Assessment Guide 2011.

4. Stakeholder Feedback

The project team conducted interviews during the technology installation phase to gather feedback from building representatives and installation contractors to gather feedback on the installation process, technologies, and benefits. Table 17 shows the individuals and entities followed by the input by role and topic followed by a summary of key takeaways.

Table 17: Individuals and Entities Interviewed for Product and Project Feedback

Interviewee(s)	Organization	Stakeholder Type	Month/yr	Interview Format
Christy Kindig, Phil Neff	City of Santa Ana	Building Representatives	Jan. 2020	In-person
Benjamin Buchanan	SBT Alliance	Contractor	July 2020	Virtual
Joshua Veblen	Alco Building Systems	Contractor	July 2020	Virtual
Marti Hoffer	Lumenomics	Contractor	August 2020	Virtual
Kenny Seeton	Cal State Dominguez Hills	Building Repetitive	Sept. 2020	Virtual
Michael DeMaria	BeMo	Contractor	Oct. 2020	Virtual

Building Representatives

- **Santa Ana City Hall (SA)** Christy Kindig is the Projects Manager for the Public Works agency. She manages their Local Government Partnership with the utility and serves as the main point of contact for the City's participation in the Southern California Regional Energy Network (SoCalREN). Phil Neff (Buildings & Facilities Manager for the City of Santa Ana) also provided input.
- **California State Dominguez Hills (CSDH).** Kenny Seeton is the building representative from Cal State Dominguez Hills. Kenny is the Supervising Building Services Engineer for CSU-DH and was the main point of contact for this project. While Kenny does not spend the majority of his time on campus in Welch Hall (the project construction site) he was the person responsible for collecting all feedback and thus had a lot of relevant information to share.

Contractors/Installers

- **Alco Building Solutions.** Joshua Veblen is the Chief Operating Officer (COO) and co-owner of Alco Building Solutions (ABS), which is an Energy Service Company (ESCO).

- **SBT Alliance.** Benjamin Buchanan is the Chief Executive Officer (CEO) of SBT Alliance which was formed in 2018 by bringing together three different lighting industry companies. The role of SBT Alliance was to update the lighting to state of the art, even in the context of a very aged architecture. Benjamin said they tuned each area to provide the exact light it required.
- **Lumenomics.** Marti Hoffer is the founder and CEO of Lumenomics. Lumenomics installed the new automated shading technologies on windows to manage heat gain and glare and create comfort for occupants for both project sites. Lumenomics works on design, manufacturing, install, and distribution to help architects and building owners make the right decisions.
- **BeMo.** Michael DeMaria is the Founder and CEO of BeMo and has been in commercial real estate since 2003, currently working with Jones Lange LaSalle. BeMo is a software platform for window treatments and their effective management and use. BeMo's role was to control louvers and roller shades in both buildings. Michael saw a need for roller shade technology and now works to sell them to commercial building owners.

Owner Interviews

Interviews conducted at both test sites with building representatives reveal a glimpse into their early perceptions of the technology installed during this project. Interviews were conducted in the same year that installations had been completed, so none of the stakeholders had a lengthy time to build opinions of the technology. Santa Ana City Hall (SACH) building representatives only provided answers related to the lighting upgrades although the shading technology was installed there. This was due to additional work underway to correct for shading malfunctions at the time of the interviews. A full interview capturing perceptions of both lighting and shading technology was completed for Welch Hall at California State University, Dominguez Hills (CSUDH).

Project Process

An area of agreement among building representatives interviewed was their need to have a full understanding of the project and to be able to communicate project details to other staff, departments, and tenants as necessary. Each site had a main point of contact and both said that they invested considerable time to understand the project and communicate it internally; they also both felt that the time invested was reasonable. Additionally, both points of contact reported that they wished their Information Technology (IT) departments would have participated earlier in the planning process of the project, and that they underestimated how much coordination and involvement would be needed with their respective IT teams. Overall, the contractors and installers interviewed reported satisfaction and success with their experience related to the installation of the emerging technology at both sites and highly ranked the products that were being installed. There were challenges that needed to be overcome to complete installation, but modifications were applied that allowed for the work to be completed.

Lighting

Overall, the building representatives interviewed from each site shared positive perceptions of the lighting technology that was installed and reported similar challenges with lighting prior to the upgrades. They noted similarly poor pre-existing conditions and challenges for their respective sites prior to the upgrades: having inefficient and costly lighting and expressing frustration with the increased maintenance of changing lightbulbs frequently. Additionally, they reported having similar challenges with certain parts of the building being either over- or underlit. When asked about the perceived benefits of lighting upgrades, all agreed that energy and monetary savings were key benefits, alongside decreased maintenance needs and better lighting for employees and tenants.

All building representatives noted that once the LEDs were installed, they were far too bright and building occupants immediately complained until the light levels were adjusted as part of the commissioning step. The contractors and installers recognized that brightness levels were a pain point for occupants once the new LEDs were installed but were not overly concerned about that as dimming could and did take place.

Shades

Only the representative from CSUDH was able to report on experiences related to the shading technology, and at the time of the interview shared that the shades were not functioning as expected while acknowledging that some additional and corrective work remained to be performed on them. Though there was initial excitement among building representatives about the shading technology and the look of the shades, the sentiment turned to frustration shortly after installation. Building occupants were troubled with the lack of manual override, and experienced blinds closing on them during meetings and when they did not want them to close. Some resorted to using makeshift props to keep them open, and generally did not understand what was needed to have them operate as desired.

The project's main point of contact suggested it would have been better to keep the project as a smaller pilot, such as one room of the whole building, to test a smaller area and not disrupt as many occupants. Both contractors and building representatives acknowledged that this facility has high sensitivity from occupants since the University President's office is located there.

Technology Benefits

The group of installers and contractors had overwhelmingly positive views of the lighting, shading, and controls technology and products being installed, but they often cited advantages not brought up by building representatives interviewed for this project. For instance, the installers talked about advantages including Internet of Things (IoT) which allows for controllability, customization, gathering of data, and technology integration. Building representatives want to hear about occupant comfort and satisfaction predominantly, so the messaging should be adjusted. Some of the installers and contractors interviewed did note other benefits that building representatives offered including thermal and visual comfort and energy and monetary savings, but it is interesting to note that building representatives did not mention the technical advantages in their perceptions of emerging technology advantages.

Given that a prominent benefit is that productivity and sales may be boosted from the installation of the emerging technologies, any market-facing materials should align with the space benefits rather than the energy benefits. Communication of the more technical benefits likely needs to be paired with easily digestible education about the technologies so that non-experts can understand and appreciate them.

Owner Specific Input

Building representative interviewees emphasized non-technical benefits of the emerging technology including occupant comfort, energy and monetary savings, and demonstrating a commitment to sustainability.

Santa Ana City Hall

Lighting upgrades will be very helpful in reducing maintenance, energy costs, and boosting occupant comfort and energy savings. Santa Ana City Hall's building manager commented that the lighting upgrades associated with the project will take the burden of lightbulb exchanges off the City. He valued the decreased maintenance, energy and monetary savings, and that it doesn't compromise comfort, which is a priority. City Hall's representative also added that the lighting upgrades save capital expenditure and energy savings which is especially important when there is little budget to pursue projects like this.

CSUDH Welch Hall

Keeping tenants happy is key in energy upgrade projects and showcasing energy and cost savings alongside improved sustainability is a benefit. The building representative at CSUDH Welch Hall agreed that the most appealing project benefits included energy savings and making tenants happy and comfortable. He said it is always beneficial for him to tout the sustainability benefits of a project to the campus stakeholders.

He indicated that communication with the occupants is important to help ensure both the success of the project and to avoid complaints from the occupants through the project progress. Early on, communication can also be used to help define what the illuminance goals of the project are (beyond saving energy).

Installer interviews

All interviewees heard feedback related to overly bright lighting levels shortly following installation. The difference in brightness levels was brought up right away by tenants at both sites. This is in part due to the process of the LED equipment installation and commissioning to set the lighting levels for each space. It is not practical to perfectly match the desired lighting levels in each space given the constraints of the existing lighting locations and the output options available for normal LED lighting products. It is much more practical to select a single LED lumen package product to apply in the majority of the fixtures and then use the dimming capability of the LED product to drop the output to meet the desired light levels in each space.

This process was employed for both projects and during the installation and initial commissioning, there were reports of high light levels. Lighting levels were quickly addressed to meet the satisfaction of the occupants. This communication should begin before the project is designed and continue through the commissioning stage to maximize the opportunity to collect feedback from stakeholders in the building.

SBT Alliance

Tenant feedback was valued and addressed. Benjamin reported that brightness levels were noticed right away in the form of complaints or concerns from tenants. Related to CSUDH, he reported there was a lot of tenant sensitivity because Welch Hall (the site of upgrades) is where the President's office is located.

He noted that one of his best practices during every installation project, which he applied in this instance, was to talk to everyone about their feedback and leave business cards for anyone who would like to follow up for anything related to the installation.

Modifications were needed for successful installations. Benjamin reported that modifications needed to take place before installation at both sites. Santa Ana City Hall was particularly challenging since it is an old building and had crumbling infrastructure.

Alco Building Solutions (ABS)

Even though some delays were encountered, it was a typical and smooth construction process. Joshua provided feedback that delays were caused by lighting shipment and connectivity issues with the dashboard. He said that the installation process was smooth overall, and that it was a typical construction project for higher education.

Lumenomics

New technology sometimes takes a long time for people to accept. Marti shared feedback from tenants received during installation. Regarding some negative perceptions, she remarked that some people will always be used to the way things were but eventually they warm up to new technologies.

Some additional advance coordination would have made for a smoother construction process, but on-the-spot planning was still effective. Marti noted that there could have been better planning and coordination pre-installation for this project. Specifically, she recommended a more well thought out plan for receiving the materials (who is receiving them, how they are labeled, where they are stored, etc.) as logistics for this part of any construction project are typically a pain point. She also stressed that it is important to plan for workarounds and communications due to any occupancy disruption early in the coordination process.

This feedback was valuable, and the project team applied it as much as possible after the initial stages of the project. However, this research project is somewhat unique in that there wasn’t a main general contractor that took care of the ordering, receiving, and storage of hardware on the site, so these comments may not apply to a more typical project.

BeMo

Occupants need more communications and training. Michael responded that since he values communication during the installation process, he ensured he communicated with everyone while at the site. He noted that it did not seem like there was sufficient internal communication prior to installations, but that people still seemed excited about the product and were having fun with it while it was being installed. He recommended proper training so tenants would know how to operate binds with controls.

Occupant Surveys

Due to the limited occupancy at both demonstration sites, the INTER Team was unable to conduct post-retrofit surveys. Based on the retrofit measures, we expect that post-retrofit surveys would have indicated increased satisfaction with lighting quality resulting from the lighting and controls upgrades. In addition, pre-programmed shade operation that proactively keeps window shades open more often may have resulted in increased satisfaction with access to window views. Similarly, handheld or computer-based shade control may have resulted in increases in occupant shade adjustment (though this could also be offset by the programmed operation, which may limit the need for occupant adjustments). In addition, providing access to control has been associated with increased overall occupant satisfaction in other settings, so providing easier access to shade control through these handheld and computer-based shade controls was also expected to result in increased satisfaction at these demonstration sites. It is also expected that these improvements could have led to increased overall satisfaction, as improvements in views and access to controls can often lead to greater reported satisfaction with a building as a whole.

Stakeholder Input Takeaways

The following is a compilation of the main takeaways that the project received from the various stakeholders involved.

Owners and Facilities

- **Education** – Provide adequate education to the facilities managers/owners so they are informed of the technology, and they can anticipate what the coordination needs are for a complex project of this nature.
- **IT Department** – Include the IT department from the very beginning of the design and construction process to ensure that adequate coordination and support is available to ensure smooth integration of the communications portions of the project into the existing IT infrastructure.
- **Facilities Managers** – Include early and steady contact with the facility manager for the building. They are the most knowledgeable staff that the owner has for the building and can help alleviate engineering and coordination problems with the contractors and other departments in the building. They are also commonly the first person to hear about issues or complaints from the occupants, so they can help ensure that the project is a success without too much difficulty.
- **Light levels** – Communicate with the owners and facilities representatives to ensure that the appropriate design approach (for light levels) is used so that when the commissioning is done, the spaces will meet the expectations of the occupants. Also communicate on the process to achieve the suitable light levels; many complaints of high light levels can be avoided if the occupants are informed of the process of commissioning and are able to provide feedback proactively in the commissioning sequence. Possibly provide a feedback form for the occupants to fill out to efficiently collect that feedback.

Occupants

- **Communication –** The occupants of the facility need to be informed of the intended changes to the facility early and with enough information on the impacts to their experience in the building so that they have an opportunity to be part of the process. This helps avoid conflict with occupants and the feedback received may be valuable to produce an end result that is the most suitable for the tasks and people in the facility.

- **Education** – provide some educational materials (videos, a crib sheet, and other forms) to ensure that the occupants can gain the knowledge of the system to interact with the lights and shades in a manner that meets their expectations.
- **Commissioning** – Take feedback from the occupants as quickly as possible to help address occupant concerns and ensure high acceptance of the system within the building users.

Designers, Installers, and Contractors

- **Messaging –** The perceived value of retrofit projects like this will be different for different stakeholders. The facilities staff will be more focused on the energy savings (possibly) and practical functional benefits like the longevity of LED lights and improved building systems monitoring. The owner and the occupants will be more interested in the aesthetic and operational (to the occupants of the spaces) benefits of improved low-glare lighting and quality shading devices. Ensure that the benefits discussed when developing the project are those relevant to the stakeholder to ensure that the best blend of design solutions are developed to meet the fullest set of stakeholders possible.
- **Project coordination –** The project is complex and requires considerable coordination among installers and the facilities management teams. In particular, the IT department is crucial to the success of an INTER project and early inclusion and buy-in by the IT department will determine the success of a project and can also have an impact on the overall project cost.
- **Specifications** – Develop a performance specification for the products and materials needed for the project to assist the contractors in meeting the expectations of the design team and the owners. This will also help ensure that competitive bidding on some products is possible, which may reduce costs. Pay attention to the performance specifications for the shading materials and the shading controls system to define the expectations of the system after the project is complete. Ensure that the specifications for the contractor installation process has clear expectations for how and who is responsible for producing a functional, clean and complete installation of the hardware and controls infrastructures.
- **Project (Systems) Integrator** – There may be a value to including a consultant or contractor who is responsible for ensuring that the various building systems (HVAC, Lighting controls, shading controls at a minimum) are all smoothly communicating and the commissioning of these systems is smooth and without gaps. In particular, the interface between the HAVC and lighting controls is a place where occupancy data for the HVAC zones needs to be collected by the lighting controls system and passed to the HVAC system. There is a potential gap in this that needs attention to ensure that this valuable source of energy savings opportunity is not missed.
- **Training of Installers** – The contractors chosen for the installation of the lighting system and shade controls need to have skills that rise above the basic lighting retrofit contractor or shading installers. Take care to ensure that the contractors are trained and knowledgeable in the systems specified.
- **Commissioning** – The light levels in the spaces were the most common points of complaint for the occupants. Consider making an initial commissioning round as part of the first installation so that the occupants do not have the chance to form a negative impression of the changes in the building before it is in its final state.

5. Project Results

Energy Savings

Analysis of potential energy savings and impacts was conducted at the LBNL FLEXLAB and based on the site baseline and post retrofit monitoring.

Lab Energy Savings

With the retrofit to the INTER system of automated shading products and LED dimmable lighting with daylight controls, the lighting energy savings relative to an existing building baseline of non-dimmable fluorescent fixtures on scheduled operation ranged from 62% in winter (less daylight dimming possible) to 76% in summer (more daylight dimming). Relative to a Title 24 baseline lighting system equipped with dimmable fluorescents and stepped dimming for fixtures near the windows, lighting energy savings were naturally reduced, but will ranged from 49% in winter to 62% in summer. Table 18 below provides details on the savings from baseline to retrofit for the configurations and per season. These are savings measured from one configuration (baseline) to an alternate (retrofit) and are not annual whole buildings estimates.

Table 18. Energy savings per test case and season (Wh/ft^2/day, %)

Savings Type	Test Configuration		Season		
			Summer	Fall	Winter
Lighting Energy	Full Window	Existing Building	10.8 (76%)	10.4 (73%)	9.0 (62%)
Cooling Load	Full Window	Existing Building	11.0 (36%)	10.9 (28%)	(no cooling)
Heating Load	Full Window	Existing Building	-1.9 (%n/a)	-1.2 (%n/a)	-2.3 (-17%)
Lighting Energy	Mid Window	Existing Building	10.6 (75%)	10.1 (71%)	9.2 (63%)
Cooling Load	Mid Window	Existing Building	11.3 (38%)	13.9 (43%)	1.1 (100%)
Heating Load	Mid Window	Existing Building	-1.3 (-44%)	-1.6 (-53%)	-2.7 (-27%)
Lighting Energy	Full Window	Title 24 Building	5.3 (62%)	5.0 (57%)	5.0 (50%)
Cooling Load	Full Window	Title 24 Building	6.0 (19%)	6.5 (15%)	5.9 (26%)
Heating Load	Full Window	Title 24 Building	-0.6 (-18%)	-0.2 (-8%)	-0.3 (-5%)
Lighting Energy	Mid Window	Title 24 Building	5.6 (61%)	4.9 (56%)	5.5 (49%)
Cooling Load	Mid Window	Title 24 Building	6.7 (25%)	8.8 (24%)	4.3 (76%)
Heating Load	Mid Window	Title 24 Building	-0.8 (-24%)	-0.2 (-6%)	-1.4 (-16%)

HVAC cooling load savings were found for all configurations when in cooling mode, with HVAC cooling load savings being very close to lighting energy savings, indicating that the majority of the HVAC load difference is due to the lower-wattage electric lighting in the retrofit case (lower wattage lighting results in less heat added to the space). Summer and fall HVAC cooling load savings were consistently higher than energy savings from lighting alone, indicating that the INTER automated shading also contributed energy savings, potentially due to solar heat gain reductions from the shades.

Some HVAC load penalty (negative savings) was observed while in heating mode, as expected. However, little time was spent in heating due to the test site's climate, so the results are less robust. For thermal comfort near the window wall, no meaningful difference was measured between mean radiant temperature in the baseline and retrofit cells for most cases (differences typically between less than 0.5 degree F to slightly over 1 degree F).

Table 19 shows the summary energy savings as a percent reduction from the two baselines and in watts per square foot per day based on the full window assessment. The savings occurred when lights in the daylight zone dimmed or went to off through the daylight controls in response to daylight from the window enhanced by the Illuminance shade product. The savings over baseline 1 of an existing building with T8s ranged from 62% in the winter to 76% in the summer. Compared to baseline 2 with a new Title 24 code building with T5 lights and step dimming controls the savings ranged from 50% in winter to 62% in summer.

Table 19: Summary of Lab Energy Savings with Full Window - W/sf/day(%)

Savings Area	Base Case	Summer	Fall	Winter
Lighting	1. Existing building: T8 (1.0 W/sf), no dimming; manual blinds	10.8 (76%)	10.4 (73%)	9.0 (62%)
	2. T24: T5 (0.69 W/sf); stepped dimming; manual blinds	5.3 (62%)	5.0 (57%)	5.0 (50%)
Cooling	1. with T8 lighting	11.0 (36%)	10.9 (28%)	--
	2. with T5 lighting	6.0 (19%)	6.5 (15%)	5.9 (26%)
Heating Savings: Some HVAC load penalty (negative savings) was observed in heating mode, as expected. However, little time was spent in heating due to the test site's climate, so results are less robust.				

In addition to the energy and illuminance findings above factors regarding the installation and commissioning of the INTER shading system were also evaluated with the following results:

- The INTER shading system is powered by rechargeable batteries and integrated photovoltaic chargers, which functioned as intended during the test (autonomous with no need for hardwired power).
- The shade controller Wi-Fi hub was successfully programmed to discover and control the blinds and shade motors. The wireless battery-powered remote control was also easily commissioned and used to adjust shade height and blind angle.

- Automation of blind tilting through scheduled actions was not effective due to minor mechanical issues (deflection of the rod holding the louvers up), so blinds tilt angle was controlled in-person by remote control or smartphone and then fine scale adjustments were made manually.
- At the time of deployment for FLEXLAB testing, there was no commercial control server or software that could implement automated blinds and shades operation based on a solar model for predicting solar angles through time.
- The ability of the reflective louvers to direct sunlight onto the ceiling deeper into the test cell was confirmed visually and through photographs for different tilt angles.

Site Energy Savings with Normal Occupancy

The calculation of retrofit savings was affected by the SIP that occurred shortly after the retrofits were completed. This provided a very short time period of post-retrofit data with normal occupancy – just 2 weeks in Welch Hall and about ten weeks in SACH. We considered ways to normalize for different occupancy levels (e.g. using Wi-Fi data) but were not able to obtain the data to attempt this.

We used the RM&V2.0 tool[6] to conduct the analysis. We fit a model using the pre-retrofit data and used that model to predict the baseline for the post retrofit period ("Pre-retrofit Baseline"). The model accounts for time of day and temperature. The retrofit savings is the difference between the pre-retrofit baseline and post-retrofit measured data.

It is important to note that the retrofit savings percentage results presented below are based on a very short time period and do not necessarily reflect the percentage savings for annual energy use. Table 20 shows the savings analysis for Welch Hall and SACH. The figure shows percentage savings as well as three metrics for how well the model fits the data i.e., in effect its predictive capability. CVRSME represents the uncertainty and NMBE represents the bias in the modeled data. The shaded cells indicate data that do not meet the default RM&V2.0 thresholds for these metrics.

Figure 10 and Figure 11 show the post-retrofit baseline and measured energy use for the total, electric, lights and HVAC for Welch Hall and SACH, respectively. These figures also show the outdoor temperature for reference.

With the caveats about post retrofit duration, we would make the following observations:

- Both sites show significant lighting energy savings of 35% and 42% in Welch Hall and SACH respectively.
- Both sites show significant savings in electricity, at 15% and 19% for Welch Hall and SACH respectively.
- Welch Hall shows significant HVAC savings of 29% and site energy savings of 26%. However, the HVAC savings includes the impact of some changes to HVAC controls implemented by the facility manager that were not part of the INTER retrofit.

[6] https://lbnl-eta.github.io/RMV2.0/

- SACH shows a more modest HVAC savings of 6% and site energy savings of 15%, but this does not include steam savings due to the data quality issues mentioned earlier. It is therefore a conservative estimate of actual HVAC and site energy savings.

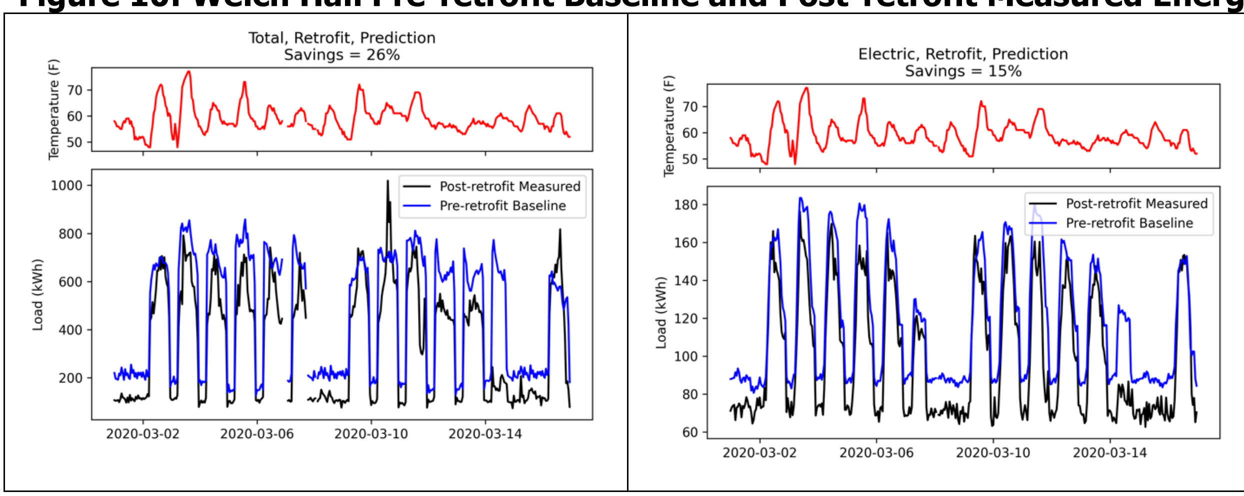
Table 20: Retrofit Energy Savings with Normal Occupancy

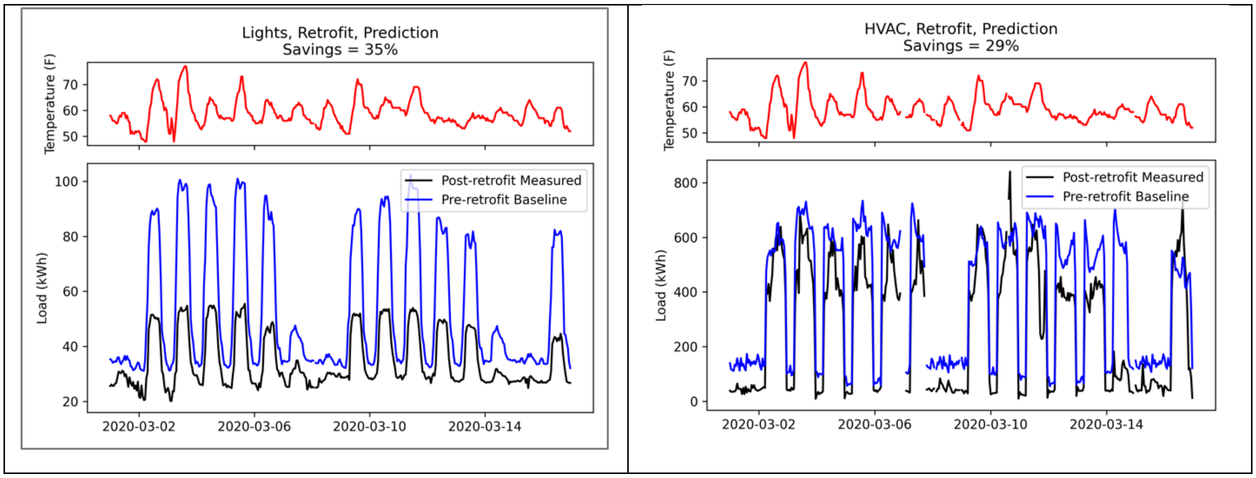
Energy Stream	Savings %	R2 (%)	CVRSME (%)	NMBE (%)
Welch Hall				
Site energy	26	78	29	-0.08
Electricity	15	83	14	0.12
Lights	35	87	18	-0.03
HVAC	29	78	34	-0.1
SACH				
Site energy*	15	91	12	-0.05
Electricity	19	96	5	-0.04
Lights	42	96	5	0.02
HVAC*	6	86	34	-0.13

Data is measured energy savings for the Post-retrofit Pre-Shelter in Place time-period. Shaded cells indicate values not meeting RM&V2.0 default thresholds for model fit.

* Does not include savings in district steam, due to erroneous post-retrofit data. These figures represent electricity and chilled water savings only.

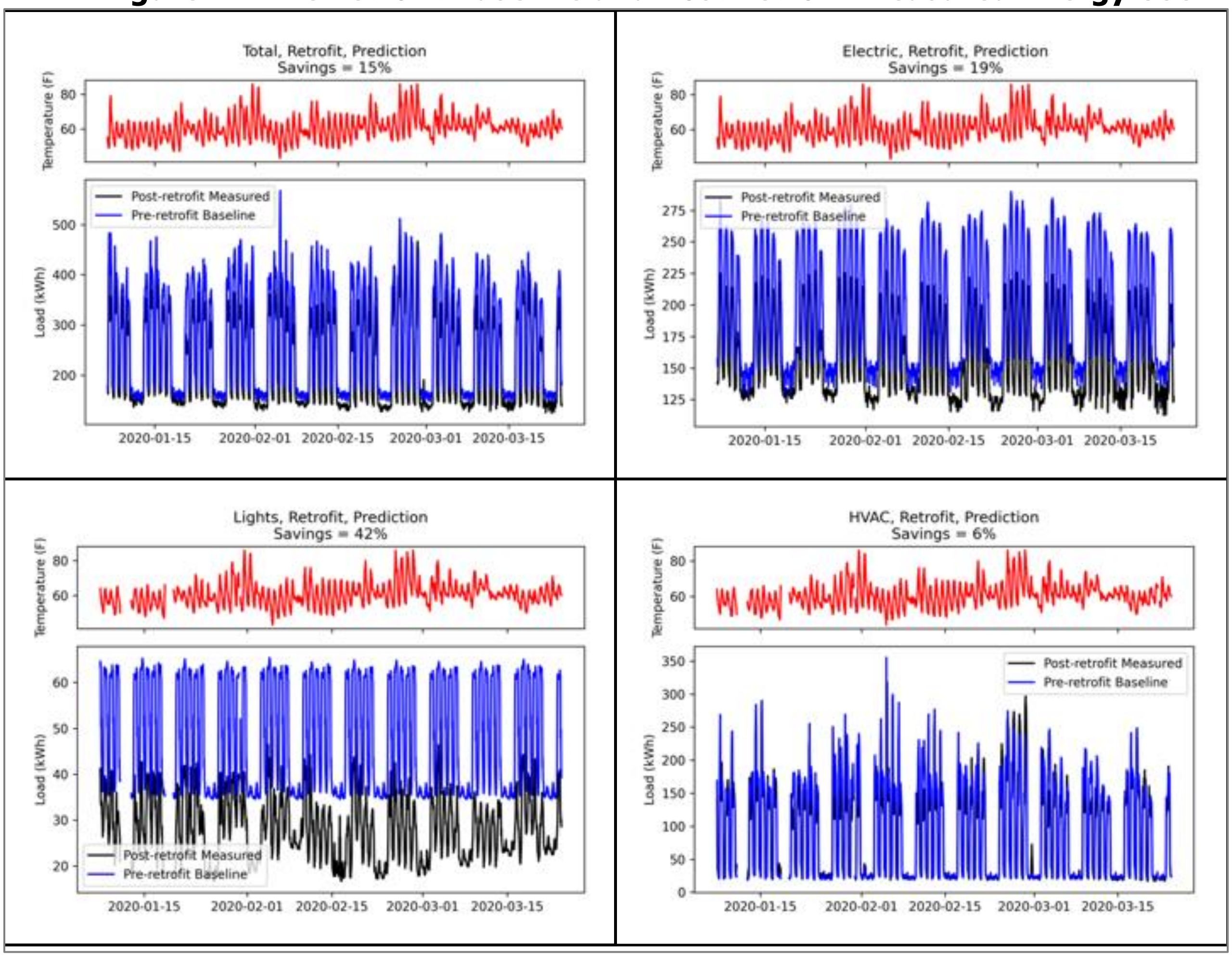
Figure 10: Welch Hall Pre-retrofit Baseline and Post-retrofit Measured Energy Use





Total site energy (top left), electricity (top right), lights (bottom left), HVAC (bottom right).

Figure 11: Pre-retrofit Baseline and Post-retrofit Measured Energy Use



Total site energy (top left), electricity (top right), lights (bottom left), HVAC (bottom right).

Economics

The INTER Team developed cost estimates for the INTER system retrofit installations at Welch Hall and Santa Ana City Hall. Because of the highly customized solution required for SACH, full costs from that retrofit are not directly comparable to more typical conditions. Cost conditions and assumptions are outlined as shown in Table 21. The cost information outlined below represents equipment, labor, and commissioning costs for the two retrofits, and do not include the cost of M&V materials and labor, or other associated research costs. The table also includes the total building area for context.

While retrofit costs shown here are normalized to building area in Table 21 and summarized in Figure 12 there is high variability of window area to floor area between the two sites and variations in retrofit approaches in different parts of each building. Window treatments are typically priced based on the area of the window, not on the floor area of the buildings. But general tenant improvements of lighting and interior features are commonly conducted in commercial real estate. The costs for this INTER package installation in real world terms was estimated at $10.50-$14.00 per square foot. This upgrade price was vetted with a commercial building real estate expert who considered it within the standard range of lighting and additional tenant improvement packages.

Table 21: Estimated Real World Retrofit Project Costs

	CSUDH Welch Hall		Santa Ana City Hall	
Field demonstration project area (square feet)	131,000		88,000	
Technology	Est. Cost	Cost per sf	Est. Cost	Cost per sf
Lighting & Controls	$715,000	$5.46	$657,000	$7.47
Shades equipment	$294,000	$2.24	$285,000	$3.24
Shades installation	$175,000	$1.34	$121,000	$1.38
Shades controls	$88,000	$0.67	$84,000	$0.95
Wiring	$40,000	$0.31	$29,000	$0.33
Shades Total	$597,000	$4.56	$519,000	$5.90
HVAC retro-commissioning	$63,000	$0.48	$57,000	$0.65
TOTAL	$1,375,000	$10.50	$1,233,000	$14.01

Note: These are estimates based on actual costs from the project with adjustments to represent margins, markup, and true market costs to remove the research project aspects from the pricing where appropriate.

Figure 12: Estimated Cost Per Square Foot of the INTER Technology Solution Set

- $5-8/ft² for full networked lighting retrofit with BAS integration
- $0.2-0.4/ft² annual lighting energy consumption cost savings
- $10-14/ft² for full retrofit package, including lighting, automated shades, and retro-commissioning

Cost Savings and Payback

The cost savings for each site was projected based on the primary energy savings area of lighting. The projected annual savings was $18,000 at Santa Ana and $14,000 at CSUDH as shown in Table 22. As the Illuminate design is an emerging product with a unique configuration of the wireless PV-powered integration the market pricing is not yet fully established. The project team does not feel the estimated project costs above should be used as a basis for determining the cost-effectiveness of the INTER system until all components are fully market ready. Payback and cost-effectiveness were thus not analyzed due to the evolving design and production of the shading system. In addition, the cost estimates represent a full retrofit estimate and do not reflect the likely scenario of 'replace on burn out' for technologies. In a replacement scenario the costs would be incremental so significantly lower.

Whereas cost-effectiveness represents in part the reasonableness of an investment by an owner, the driver for this package is more focused on the value to tenants/occupants. Lighting and shade system benefits are a focus of the Technology Transfer products and activities. Few if any shades are selected based on cost-effective criterion as they fall under interior design and comfort features expected in today's commercial offices. The INTER package essentially offers a 'bonus' of proven energy cost savings over other products and projects under consideration.

Table 22: Projected Annual Lighting kWh and Cost Savings by Site

Location	Lighting kWh Savings	Lighting Energy Cost Savings ($)
Santa Ana City Hall	200,000	$18,000
CSUDH Welch Hall	170,000	$14,000

Lessons Learned

The lessons learned are organized around six areas that capture the findings with the sites and overall challenges and then focus in on each of the four technologies specifically.

Application Assessment

The INTER system is an ideal approach for office spaces that meet the following requirements:

- There is generous daylighting availability in the building spaces.
- The spaces benefit from daylighting that is not blocked or reduced by external shading (trees or other nearby buildings), dark window glazing tint, and substantial overhangs.
- There is a lighting system that is ready for an LED retrofit (or has been recently retrofitted and includes a NLC system, or more preferentially, an LLLC system.
- The implementation of an LLLC control system will provide the best and most responsive lighting control to reduce energy consumption when the conditions are suitable.
- There is an HVAC system with adequate zoning and the control system to reduce the airflow with the right conditions.

The automated shading system is intended to provide an improvement in the visual environment of the spaces in the building and are not designed to produce substantial energy savings compared to a building with manual shades. There are a number of reasons for this, but the main one is that the shades will reduce daylight penetration much of the time and this may result in slightly higher energy consumption than a building without the shading system (depending on the manual settings). However, the intent of this system is to provide high energy savings while still yielding the best possible visual environment for the occupants to perform their duties.

Project Challenges

There were a number of technology challenges that the INTER Team needed to overcome through this project. This listing is dedicated to the technological challenges, while Section 5.3 below addresses the largest external factor; the COVID-19 pandemic. Following below is a list of the challenges, the solutions developed, and in some cases, the efforts required to resolve the issues.

- **Emergency lighting fixture quantities at Welch Hall** – The original lighting design at Welch Hall had a very high percentage of light fixtures on the emergency lighting system. This far exceeded the emergence egress illuminance lighting requirements in the codes. The lighting system was converted to an LLLC system using Enlighted controls. When this conversion takes place, every emergency light must have a UL924 compliant relay installed, and additional continuous power wiring run to the fixture to ensure that the lighting control system will bypass control to the emergency lighting system to ensure that adequate light levels is present when an emergency occurs. This relay installation process is expensive and completely unnecessary for luminaires that are not needed to meet the emergency lighting requirements. The INTER Team contracted with an electrical engineering team to redesign the emergency egress lighting plan to reduce the post-retrofit emergency lighting to meet the requirements using the minimum quantity of fixtures possible. The remainder of the pre-retrofit emergency lights are now not treated as emergency lighting and did not require this expensive failsafe relay.
- **Emergency lighting fixtures commissioning at Welch Hall** – The installation of the emergency lighting continued to cause problems because the fixtures that are wired with the UL924 relay were connected incorrectly. The lighting controls wiring for a sophisticated control system such as the Enlighted system (and especially when adding in the complexity of the UL924 relay) requires a properly trained electrician to ensure that the system is wired properly and is fully functional. This system was wired improperly at the beginning and the problems were observed and work stopped until the solution was found. The contractor (SBT) investigated and discovered that while the system was wired such that there was power at the lights, the proper wiring was not completed to allow the normal lighting control system to function during the normal operation of the building. In effect, the emergency bypass was connected continuously. Once this wiring error was corrected, all the emergency lighting functioned as intended.
- **Wireless battery-powered sensors will fail** – The existing lighting control system in the Santa Ana City Hall was a Daintree system that was installed in about 2012. This system was installed with battery-powered occupancy sensors and wireless communications to reduce the cost of installation. When the INTER Team began field surveys, we noted that most of the

occupancy sensors did not function properly and discovered that the facility managers had not replaced a battery in any of them since the time of initial installation. It was unclear if they were even aware that there was a battery maintenance requirement for that older system. As a part of making the lighting upgrades, we removed all the older sensors and installed a new wired sensor system to ensure that the controls do not have the same battery maintenance requirement after completion of the retrofit.

- **Communications between the lighting and HVAC systems at SACH** – The Daintree controls system does not include the capability to communicate through BACnet to the HVAC system. This is a significant shortcoming of this system currently, and makes certain aspects of the HVAC RCx impossible, most specifically employing the occupancy information to power down the fan motors when the HVAC zones are unoccupied. The INTER Team adjusted the Guideline 36 RCx plan for SACH because of this to maximize the savings within the capabilities of the installed system.

- **Limitation on existing HVAC controller boards at SACH** – The existing VAV box controllers have a limitation of only three programmed settings within the memory f the boards. This forces the INTER Team to compromise further on the ideal Guideline 36 RCx plan. These limitations are mostly due to the age of the HVAC controls equipment, but without an expensive controller replacement, a better solution is not possible.

- **Shading operating system control limitations** – At the outset of the project, Rollease intended to have a cloud-based shading control system that would be used to manage the shading systems for the buildings. Initial testing on the available system proved that the Rollease product was insufficiently developed and was not designed for the size of buildings (with hundreds of shade motors in hundreds of rooms). While it may be suitable for residences and small office buildings, it would not meet the controls capabilities that were needed by the INTER Team. The solution was to move the controls responsibility to another company; BeMotorized (BeMo). They have also partnered with Rollease for large building installations of this kind in part because of the coordination that they have developed through this project.

- **Shading controls hardware power source limitations** – The Rollease controller hubs require low voltage power normally supplied through a plug with a transformer and are intended to be installed in a space with that method of power. However, this forces the hubs to be located in the accessible workspaces rather than up in the plenum for the floor where a controller would normally be installed so that it is away from access to avoid damage or loos of the hub. It is not permitted by most building codes to place line voltage receptacles in the plenum space for a permanent installation, so an alternate solution needed to be found. This limitation was resolved by supplying power over ethernet (POE) to the locations that the hubs were needed and then using an adapter to convert from the POE cabling to the normal power connector on the hub.

- **Shading controls hardware bandwidth limitations** – The hubs proved to be a source for yet another technological problem that became apparent as the project progressed. There is a limit to the number of separate motors each hub can connect to consistently. They have a stated limit in design that was 30 motors, but the INTER Team found that we were unable to have more than approximately 25 motors connected before the connections would become unstable. This did not end up being a limitation in most parts of the building because the coverage range would limit the hub with distance, but in the corners of Welch Hall, there are enough motors in range to exceed this limitation. The solution was to increase the number of hubs in these locations, but this presented a problem with the POE because these are typically at the end of the POE runs and the available power was limited. The details were resolved to provide sufficient power and increase the number of hubs to meet all the motor connection needs.

- **Limitations on the energy monitoring system technology** – The INTER Team deployed many different sensors on this project, with many current and voltage meters in each building supplied by eGauge. These meters were connected to a cloud data collection service supplied by Senseware. The Senseware system is a sophisticated mesh network communications system that will collect outputs from the meters and then transmit them to the cloud for archiving and analysis. There were issues with coverage range of the Senseware nodes and a distinct limit on the number of node bounces that a data stream was permitted to occur before the data would no longer be passed along the mesh network. This limit is seven bounces and eight total nodes. This undocumented limitation caused a considerable amount of effort by the INTER Team to resolve missing or dropped data streams in the system, but with the help of Senseware, the limitation was discovered. and we made changes to the node locations to try to reduce the number of bounces needed to get from the farthest nodes to the main gateway. This solved the problems.

- **IoT and security concerns** – The IT managers for both buildings expressed concern about having wireless communication systems in their buildings that were in any way connected to the IT systems that are handling data and other sensitive information. The concern is a real issue because extraneous building systems have been used in the past to gain a back-door access point into an otherwise closed and well-secured IT system. The solutions for this were different in each building. In Welch Hall, the INTER Team worked with the IT manager to quarantine the ports needed to supply cloud connectivity within the larger communications IT system. They reviewed the hardware, monitored the installation, and checked the hardware to ensure it had sufficient security and didn't allow a portal into the system. In SACH, the IT manager refused to permit the shade controls onto the IT system, so we employed a cellular modem to communicate the information from the systems to the cloud.

- **Solar panel performance** – The solar panels that provide the energy to charge the batteries in the shades have proven to be a source of problems that the INTER Team worked to resolve as well as possible. The solar panels were intended to be sufficient for all the energy needs in the shades in the building, even on the North sides and under overhangs. However, this proved to not be correct and many of the batteries drained down until the shades stopped working. The INTER Team worked to understand the extent and severity of the problems and relay that information to Rollease to develop a solution to the problem.

Rollease provided information that they had updated the solar panel circuit boards after shipping the orders for this project, and we tested the newer generation of solar panels (Gen III panels). The Gen III panels proved to be superior to the Gen II panels and many of the previous panels in the buildings were replaced with the Gen III panels.

However, this did not completely resolve the charging problems that the INTER Team discovered. North side windows and windows with overhangs were still not able to charge. Further exploration revealed that there was a possible alternate solar charging approach that was considered by Rollease but had been rejected in the early phases of the project. Communication with the developers of the circuitry for those solar panels indicated that this solution would be sufficient to resolve the charging issues on the North sides of the buildings but not in the overhang situations.

For the overhang conditions, the only solution was to wire the shades to a low-voltage power supply in the building. This work was completed with the assistance of Rollease and Lumenomics.

By Technology Type

This section provides the key successes and challenges by technology type.

Lighting

Successes:

- LEDs, NLC, LLLC are all mature and performed well.
- The technologies are well understood by contractors and easy to specify.
- Lighting provided solid savings at both sites and is the 'lynchpin' to meeting overall whole building savings.
- Retrofit kits where the contractor simply does a substitute of lamps rather than a whole fixture upgrade is the best gateway in terms of time and cost to get lighting upgrades.

Challenges/Barriers:

- LEDs are normally too bright at install so you need to warn the operator and occupants regarding expectations and commission the system quickly.
- There are typically internet of things (IoT) and security concerns around wireless communications connected to systems handling sensitive data so you have to work early and often with the IT department
- The markets remain well below potential for integrated controls and LLLC.

Shades

Successes:

- Users expressed excitement with the improved environment, personal operations and comfort.
- The upper daylight dedicated louvers increased daylight penetration and savings.
- A new control vendor (BeMotorized) partnered with the shade manufacturer (Rollease Acmeda) and expanded their artificial intelligence capability and their product offerings through this project.

Challenges/Barriers:

- The shade controls and Gen 2 PV panels were insufficiently developed for commercial application during the project.
- The controls hardware needs to be hard wired which increased installation complexity and time.
- Solar panels: under certain orientation and obstructions the charging performance was inadequate, and glazing variability impacts the solar charging capability.

Retro-commissioning (RCx)

Successes:

- The RCx for this project demonstrated improvement in HVAC control settings.
- RCx is a low-cost approach to optimize buildings as there are rarely any materials investments – just labor.
- RCx is very synergistic with the integration strategy of occupancy and lighting sensors to assure additional savings.

Challenges/Barriers:

- Existing VAV box controllers had limitations and communications issues with lighting systems that limited some HVAC RCx opportunities.
- RCx agents' territory is limited to HVAC – lighting system integration is not their purview.
- Tale of 2 buildings: Range of building managers technical knowledge, time and funds. Results were dramatically greater in the site with a deeply knowledge and engaged facility manager.

What to do Differently

Lessons in this project can support future research and implementation projects that pursue integrated technologies in existing buildings. The following are five key changes we identified from this project:

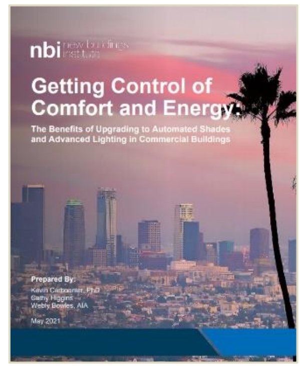
- Bring in the internet technology team early.
- Pilot new technologies in a subset of the participating building first.
- Manage occupant and operator expectations before the retrofit (LED brightness, shade operations).
- Identify and employ a systems integrator.
- Provide detailed specs for the shade installer.

6. Technology and Market Transfer Activities

Market Resources

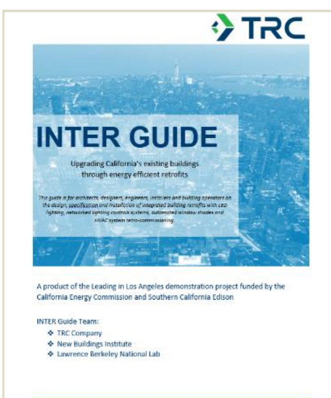
An early deliverable for this project was the Technology Transfer Plan that identified key resources needed to overcome barriers "*to provide design guidance on the system and a business-decision making brief that has a compelling rationale and data for retrofitting with this system.*" The INTER team has developed a set of market-oriented materials to support the technology transfer with a variety of market entities. These market products are listed below with their market-side description, followed by the report Market Connection section describing the LiLA activities and entities. All the products below are located on the project team website – Leading in LA website.

Getting Control of Comfort and Energy



Interior lighting and window shading innovations have advanced leaps and bounds in the past two decades. Each innovation offers benefits to existing buildings, ranging from improved occupant comfort and wellbeing to significant energy savings. Geared toward building owners and operators, this market facing guide outlines the benefits and best practices to implement lighting and shading retrofits in today's market.

Installer Guide



The INTER Guide enables architects, designers, engineers, installers, and building operators to maximize the many benefits of the INTER Technology Solution, integrating networked lighting controls (NLC) systems and automated window shades retrofits with HVAC system retro-commissioning.

The guide introduces the benefits of integrating LED lighting with networked lighting controls, automated shades, and HVAC retro-commissioning; defines project roles and considerations; provide guidance for design, specification, and installation of these integrated retrofits; and resources for building occupants and operators to better understand these new systems.

Three key messages of the guides are that the INTER system (1) is valuable for supporting occupant comfort and control, (2) can be pre-customized and installed in occupied spaces without electrician costs, and (3) produces higher savings than individual technologies in isolation while providing higher user amenity.

Reopening and Retrofit Blog White Paper, Checklist

Posted on NBI's COVID-19 recommended resources page: Office Buildings: *Reopening a Healthy Indoor Environment for Occupants and the Planet.* Items supported by the EPIC LiLA Project encourage upgrading existing buildings with integrated solutions as a path to reopening a better workspace.

NBI is engaged in improving buildings/ functional design, efficiency, operating practices, comfortable occupancy environments, and low-emissions to benefit people and the planet. The COVID-19 pandemic demanded the study of the relationship between buildings, ventilation, and occupants. In response, NBI researched dozens of industry journals and guidelines for reopening offices safely, focusing on the energy-using systems in buildings. From this research, four resources were developed to support those responsible for returning office occupants safely to their environments.

nbi new buildings institute

Retrofit and Reopening Recommendations for Offices: A Quick Checklist

Introduction

This resource provides facility managers and building owners with a brief overview of why the COVID-19 pandemic is a compelling time to consider system upgrades. It provides a set of retrofit options, recommended policies, and operating practices for reopening and occupying buildings. The recommendations are derived from an extensive collection of industry standards and professional guidance distilled down to a quick checklist.

A Safe Climate—Indoors and Out

RESOURCES:

- **Reopening Office Buildings:** Creating a Healthy Environment for Occupants and the Planet. A brief white paper with an overview and summary of the multiple building systems that affect occupants' return to a safe indoor air environment, energy use implications, and best practices recommendations.
- **Retrofit and Reopening Recommendations for Offices:** A Quick Checklist. A resource for facility managers and owners to consider retrofit options, policy recommendations, and operating practices for reopening and occupying office buildings.

Two blogs that provide the context for the recommendations:

- **Blog #1: Buildings' Impact on Pandemics**. This cites and summarizes the critical relationship between buildings, climate, and pandemics noting why we must address people and the planet.
- **Blog #2: Future Proofing Buildings for a More Resilient Tomorrow**. Focused on the compelling need to address existing buildings' energy and emissions impacts during this time of occupancy reduction.

Case Studies and Videos

Both demonstration sites were the basis for a hard-copy printable case study and a video case study. The case studies provide a concise and graphically rich story, and in the case of the video visually interesting dynamically explaining the technologies and their interaction along with interviews with project and building representatives. Below is a synopsis of each sites case study content.

Santa Ana City Hall

The City Hall building in Santa Ana sought to improve its indoor environment and save on energy costs with automated shades, upgraded lighting fixtures, and networked lighting controls. The project updated the existing T8 lamps to LEDs and controlled the lighting with the existing Daintree system, resulting in over 40% lighting energy savings. The solar-powered automated shades by Rollease Acmeda provided operator pre-settings for daylight responsiveness and occupant customization for glare and heat control. The retrofit covered over 2,400 light fixtures and 481 windows in this 127,000 square-foot office building.

California State University Dominguez Hills Welch Hall Building

The Welch Hall building on the California State University Dominguez Hills campus partnered with the project team to retrofit their existing Enlighted lighting system and manual shades to the INTER package – which included LED lighting with Luminaire-level lighting control (LLLC), solar-powered automated shades, and HVAC retro-commissioning. Lighting savings was 35%, and the site savings exceeded 25% whole building. This extensive retrofit covered nearly 2,000 lighting fixtures and over 400 windows in this 183,000 square foot administrative and classroom building.

Technology Case Study

Several manufacturers offer innovative window treatment solutions that allow daylight into spaces while controlling for glare and allowing views to the outdoors. In this case study, we focus on Indoor Sky's Daylighter Shading System. The system has two parts: automated roller shades for the view portion of the windows, and automated lightshelves above.

Making Impact: Connecting Results with the Market

Transferring a technology to the building industry relies on making market connections. The core strategies used for this project followed an A-B-C approach: A) industry visibility: to have the industry see the change widely mentioned in their news and events through publications and conferences, B) industry connections: to make direct industry outreach with influencing organizations, and C) programs and policies: to move the technology forward with programs and policies.

NBI and its team conducted over 45 total tech transfer activities touching an estimated 30,000 parties. In some cases, a single party can in turn influence a multitude of buildings so the connection count simply reflects points of contacts or subscribers. The types and number of tech transfer activities are summarized in Table 23 followed by a summary list organized by type.

Table 23: Tech Transfer Types and Counts

Strategy	Tech Transfer Type	Count	# of Contacts
A. Industry Visibility	Publications	13	Estimate 30,000 +
	Conferences and Webinars	14	
B. Industry Connections	Industry Direct Connections	14	
C. Program and Policies	Program Connections	4	
	Policy Connections	1	
	Total	46	

Technology Transfer Activities List

A. Industry Visibility

Publications

1. The Continental Automated Building Association (CABA) Fall 2021. *Impacts of Automated Shading in Building Projects* Study on Shade Technologies will include wireless PV powered shades due to this project (pending)
2. Forbes Magazine July 2021. How to Improve Employee Well-Being and Save Energy in a Post-Covid-19 Environment June 2021
3. The Energy Coalition (TEC) Newsletter June 2021
4. NBI Newsletter June 2021
5. Southern California Regional Energy Network (SoCalREN) Newsletter Fall 2021 (pending)
6. Engineering and Construction Management (ECM Magazine) article May 2021
7. Integrating LLLC Technology with Building Systems
8. U.S. DOE Newsletter March 2021. California State University – Dominguez Hills Taps into Benefits of Integrated Lighting
   NBI Blogs March 2021. Buildings' Impact on Pandemics and Future-Proofing Buildings for a More Resilient Tomorrow
9. NBI White Paper March 2021. COVID White Paper: Reopening Office Buildings: Creating a Healthy Environment for Occupants and the Planet
10. NBI Checklist March 2021. Retrofit Checklist: Retrofit and Reopening Recommendations for Offices: A Quick Checklist
11. U.S. Department of Energy (DOE) 2021 Integrated Lighting Campaign Recognition December 2020. Award application submitted and pending awards. Recognition Website
12. The American Council for an Energy-Efficient Economy (ACEEE) Summer Study August 2020. *Blind to Blinds: Opening Our Eyes to Savings from New Automated Shading Systems*
13. Architectural Products Magazine, page 46 July 2020. NBI Study Keys in on Optimizing Automated Shading

14. Yahoo Finance March 2020. Santa Ana Innovation Award for Retrofit Strategies

Conferences and Webinar Presentations

1. Building Owners Management Association (BOMA) Greater Los Angeles, Long Beach Regional Council LA Chapter July 2021
2. San Diego Climate Collaborative Webinar June 2021. Emerging Technology Case Study and Re-entering offices
3. NBI Webinar June 2021. Existing Building Retrofits: An integrated Solution Set for Energy and Occupant Benefits
4. NBI Fellows Presentation June 2021. LiLA team presented to a set of esteemed and influential industry professionals on the project.
5. National Institute of Building Sciences (NIBS) Building Innovation Conference September 2021. Submissions submitted to present on LiLA. (pending)
6. New England Clean Energy Council (NECEC) Webinar August 2020. Emerging Technology Case Study: Retrofit Shading Package. Advocating for national demand for the INTER System.
7. Better Buildings Summit Conference June 2020. The Next Frontier in Lighting: Getting Connected with the Integrated Lighting Campaign
8. California Universities Sustainable Conference at CSUDH June 2020. *Energy Efficiency Efforts & Sustainability Update at CSUDH*
9. ETCC Conference May 2020. Leading in LA: *Shading as a Gateway Technology to Deep Retrofits*
10. PG&E Webinar November 2020. Where are we with Integrating Lighting and Whole Building Controls?
11. The American Council for an Energy-Efficient Economy (ACEEE) Conference August 2020. *Made in the Shade: Advocating for Shading Automation*
12. Behavior Energy and Climate Change (BECC) Conference November 2019. Made in the Shade: Advocating for Automation of Shading in Existing Buildings
13. The American Council for an Energy-Efficient Economy (ACEEE) Conference October 2019. Scalable Deep Energy Retrofits in Commercial Building
14. Lightshow West September 2019. National Conference on Energy Efficiency as a Resource Leading in LA – A CEC EPIC Demonstration Project

B. Industry Direct Connections

1. Building Commissioning Association (BCxA) July 2021. BCxA will use some of the project RCx findings to support their work with the White House Council on Environmental Quality and share findings with California BCxA members**.**
2. Continental Automated Buildings Association (CABA), 2019-2021 Engagement with the major shade manufacturers through our role on the advisory board of the impacts of shading study.
3. San Diego Green Building Council. Sharing results to the council. (pending)
4. Building Owners Management Association (BOMA) LA Chapter Webinar. July 2021.
5. California Department of General Services (DGS) - Division of the State Architect. May 2021 meeting and links shared on project findings and resources.
6. California Lighting Technology Center (CLTC). Direct staff connection on results and resources. June 2021
7. California Energy Alliance May 2021. Meeting with the Executive Director.

8. San Diego County Public Buildings May 2021. Meeting with the Energy and Sustainability Division at County of San Diego.
9. Southern California Regional Energy Network (SoCalREN) (pendng). Program Team Meeting.
10. San Diego Climate Collaborative May 2021. Meeting with the Program Manager.
11. Jones Lang LaSalle (JLL) September 2021. Inclusion of shades within their tenant communications and tool.
12. Bagatelos Glass and LuxWall VIG March 2021. Meeting with the CEO.
13. Pacific Energy Center Course Fall 2020. Integration on Lighting Controls and HVAC course.
14. Southern California Electric (SCE) September 2019. Tour SA site with SCE.

C. Programs and Policies

1. Southern California Electric (SCE) April 2021. Program Incentive eligibility for Shades and for INTER Package through the new NMEC program. Other CA utilities are adopting NMEC.
2. WELL Building Standard June 2021. Connecting the WELL Building Standard and the INTER system.
3. Southern California Edison (SCE) September 2019. Site tour and presentation on the project with efficiency program staff from SCE.
4. Northwest Energy Efficiency Alliance (NEEA) Product Council January 2020. Met and shared Leading in LA to consider INTER package within NW programs to create added attention.
5. Policy recommendations for codes and modeling delivered to CEC codes team.

The full Technology Transfer report includes more description for the items listed above.

7. Conclusions

Despite unique challenges at each site, and the emerging issues of the new technology components, the demonstration project and research will help advance integrated technologies and lower energy use in existing buildings. The project met its primary research objectives, and its results and conclusions support the Commission and our industry's ongoing work to influence buildings to be better for people and the environment.

Primary Findings

- **Existing buildings can take 20% off their energy use without a major renovation.** The INTER technologies do not require major disruption of occupied buildings. The technologies delivered strong lighting savings of 35-42%, HVAC savings of 6-29% and whole building savings of 15-26%.
- **LEDs, controls, LLLCs and retrofit kits lead the system.** The upgraded lighting system is delivering substantial energy savings due to overall lighting loads reductions from the mature LED technologies, controls with institutional tuning, and daylighting responsiveness. Control at the luminaire-level (LLLCs) offers optimum savings and highly valuable data at the occupant level that optimizes the HVAC system. Retrofit kits allow upgrades to the existing fixture at lower cost and faster implementation.
- **Project spurred new products.** A new PV powered panel will address site solar obstructions on windows and expand the opportunity for wireless, non-obtrusive, and more affordable technologies due to the absence of hard-wiring and associated labor costs. The new control system now provides operators real-time shade performance data and user preferences with increased machine learning.
- **HVAC tuning (RCx) remains a valuable efficiency strategy.** This project mirrored the numerous studies that show that for no capital costs a competent HVAC controls company can tune up the control sequence and deliver solid energy savings.
- **Integrated delivery of multiple technologies through a single vendor did not advance.** The project intended to demonstrate "Lighting as a Service (LaaS) that extended into the shade products due to the integration of the lighting sensors, shades and HVAC. While the lighting installation did occur through a turnkey model and remains a viable technology for LaaS and potential subscription approaches the shade technology is still too independent in production and complicated in installation.
- **M&V methods evolve due to lack of occupancy.** The COVID shelter in place forced some innovative thinking about how to measure the energy impacts of the new system. The INTER Team achieved calculations and results that are relevant to the project and provided a narrative of the actual impacts of the system changes on a building, even though we had only a brief period to compare the baseline and post-retrofit results.
- **Shade automation takes training.** The absence of effective and contemporary operational and interface training materials drove the project to develop a video for users and owners. The solution is supported by QR codes that are available to scan with a smart phone to gain local access to shade controls for transient occupants. This solution is a novel approach to broaden the availability of the shade controls to any user

with appropriate permissions. Installer trainer guidance was also needed and created. Clear specifications in bid documents will help owners, contractors and installers.

- **Spotlight should be on the value to the 'three Os' – owners, operators and occupants.** Preliminary feedback from occupants and owners indicates an improvement in indoor environmental quality. The quality and functionality of the new shades is higher than those previously installed in the buildings, and the aesthetic improvement is substantial. The roller shades allow view and connectivity with the outside even when closed. Operators gain energy and space use information from the integrated lighting controls. The project focused on benefits to these three Os in materials and outreach.
- **Performance specifications for shading systems are critical and mostly absent.** To advance this technology and assist the contractors in meeting the expectations of the design team and the owners there must be clear specifications. This will also help ensure that competitive bidding on some products is possible, which may reduce costs. Specifications include the shading materials and the shading controls system to define the expectations of the system after the project is complete. The technical "INTER Guide" for installers from this project helps address these barriers.
- **System integrators are a new, but highly valuable, role for commercial building retrofits.** A system integrator is responsible for ensuring that the various building systems (HVAC, lighting controls, shading controls at a minimum) are all smoothly communicating and the commissioning of these systems is smooth and without gaps. In particular, the interface between the HAVC and lighting controls is a place where occupancy data for the HVAC zones needs to be collected by the lighting controls system and passed to the HVAC system.
- **Micro-PVs for technology power support building electrification and are an emerging and important building integration factor.** Self-powered technologies, like the project tested automated Illuminate™ shades, can help balance the growth in building electrification and support grid optimization.

Key Takeaways and Recommendations

Figure 13 is a brief roll up of the depth of information above and throughout this final report.

Figure 13: Leading in LA Research Takeaways

Recommendations

The research team distilled down the following five recommendations to the Energy Commission to further advance California integrated retrofits.

1. Advance market adoption, not technology, is the priority for investment. The primary sectors to prompt are large private offices, government offices, education and hospitals, in that order for likely interest and acceptance.
2. Build workforce awareness and trainings. Automated shades with integrated controls lack an informed workforce and the application of reliable specifications in bid documents. Use the 'INTER Guide' for installers developed through this project to continue to build awareness and conduct trainings.
3. Spotlight existing building upgrades in news and media. Emphasize how upgrades help deliver the health and control occupants expect post-Covid and support owner asset appreciation goals and climate targets. Shift shades from interior décor item to energy and occupant comfort necessity. For shades to realize their potential as an integrator for daylighting and energy savings they need to be viewed as a technology rather than 'window dressing'. Identify shades as a valuable technology in Energy Commission and utility news, literature, lists etc.
4. Further push on the under-adopted but mature LLLC/NLS technologies. Work with utilities, lighting vendors, contractors, and commercial real estate to adopt these as the gateway technology to integrated systems with HVAC and space utilization.
5. Research improved micro-PVs and controls for technology-level power at buildings. Self-powering technologies for integration and site electricity generation helps balance the building and the grid and offsets load with the growth of electrification.

8. Benefits to Ratepayers

Technology and Package Benefits

The combined measures of the INTER system package are designed to provide synergistic benefits greater than the sum of the benefits of each measure individually. Benefits from the INTER system include energy, operational, and amenity benefits.

Energy benefits from the INTER system leverage the interactive and synergistic benefits of the combined measures. For example, the daylight redirecting portion of the window shades enables the daylighting controls to reduce energy use even during conditions when the view portion of the shades need to be closed to prevent glare or excess heat gain. In addition, the sensors included as part of the NLC can be integrated with HVAC retro-commissioning control sequences to provide occupancy-based HVAC control where system zoning allows.

Operational benefits of the INTER system technologies include the potential for future improvements and flexibility. By implementing the communication network infrastructure, and networked devices ("internet of things", or IoT), building systems can be more easily upgraded when new software becomes available, and systems and controls protocols can be adjusted to accommodate building reconfigurations or changes in use.

Amenity benefits from the INTER system package include the aesthetic improvement of new shades systems, as well as improved access to views and daylight through the automated shades that open to views when conditions permit, and automatically close to prevent glare when needed.

More broadly, the INTER system benefits from a "systems-approach" strategy. Recent research and development efforts, like the Leading in LA project, have produced measure packages that can take advantage of the individual measure savings but are also open to opportunity for additional savings through the bundled approach. Some of the potential benefits of a package of bundled measures include:

- A systems-approach can promote energy efficiency in a greater range of opportunities because without the proper planning, design, and implementation the peak benefit conditions of one device may not be coincident with the peak benefit of other devices.
- The systems-approach will likely be more capable of future operational and efficiency enhancements due to the connected nature of a building system that incorporates the communications necessary to accommodate integration with other complimentary building systems.
- A systems-approach can take advantage of the overlap in work needed for installation and setup with other measures to reduce the costs of each individual measure, as well as mitigate the risk that repeated operational disruptions become a barrier to implementation.
- The systems-approach can leverage the savings from high cost effectiveness measures to cover measures that are lower in cost effectiveness to produce higher total energy savings in the building.

Non-energy benefits of the INTER system are the reason for adoption. The INTER system supports the three "Os" of owners, occupants and operators and as shown in Figure 14.

Benefits of Automated Lighting and Shading Systems

Owners
Modernized building
Reduced operating costs
Higher tenant satisfaction

Occupants
Personalized control
Thermal comfort
Elimination of glare
Maintained views

Operators
Centralized data and control
Reduced maintenance of lamp change outs
Reduced comfort complaints

Figure 14: Non-energy Benefits to Owners, Occupants and Operators

Market Application

Statewide Economic Savings Potential

This research aimed to develop and test a scalable retrofit solution to address energy and carbon emissions associated with existing buildings. Supporting the development of commercial and pre-commercial building technologies has advanced the market potential of a retrofit package approach aimed toward lighting and HVAC savings coupled with occupant benefits. Ratepayers will benefit from lower emissions and energy costs in buildings that have a new approach to save on energy.

Extrapolating from the measured energy savings described above, the INTER team estimates an average total energy savings of 29% in the retrofitted portions of a building. Based on that average savings, the team estimates a potential statewide savings 2,396 GWh, equating to 1,749 M pounds of $CO2$ savings, over 15 years, assuming an adoption rate of 2% of suitable building area per year.

Table 24, below, summarizes the estimated statewide energy savings impact of the INTER system retrofit package. Though the INTER package is designed primarily for office markets, the team estimates that the approach is also suitable for a portion of the state's School (60% of building area), University (50%), Medical Office, and Miscellaneous (30% each) sectors.

Table 24: Estimated Statewide Energy Savings Impact of INTER System Package

	Annual Existing Consumption (GWh)	Combined Measure Savings	Suitability of Bldg. Area (% of area)	Technical Potential Savings (GWh)	Annual Retrofit Adoption Rate	Total Adoption Potential Over 15 years (% of area)	Market Potential Energy Savings (GWh)	Consumer Savings (M $)	CO2 Savings (M Pounds)
Large Office Bldgs	18,902	29%	100%	5482	2%	26%	**1433**	**224**	**1046**
Small Office Bldgs	3,567	29%	100%	1034	2%	26%	**270**	**42**	**197**
School	2,683	29%	60%	467	2%	26%	**121**	**19**	**89**
University	2,149	29%	50%	312	2%	26%	**81**	**13**	**59**
Medical Office	10,172	29%	30%	885	2%	26%	**230**	**36**	**168**
Miscellaneous	11,505	29%	30%	1001	2%	26%	**260**	**41**	**190**
TOTAL	**48,978**			**9,180**			**2,396**	**375**	**1,749**

GLOSSARY

Term	Definition
CSUDH	California State University Dominguez Hills
CVRSME	Coefficient of Variation of the Root Mean Square Error
HVAC	Heating, Ventilation, and Air Conditioning
INTER	Integrated Technologies for Energy-efficient Retrofits
NMBE	Normalized mean bias error
R2	R-squared, statistical coefficient of determination
RCx	Retro-Commissioning
RM&V2.0	R package for performing advanced measurement and verification 2.0
SACH	Santa Ana City Hall

REFERENCES

All content in this report is original from this research unless noted as a ‘source’ in a table or figure.

APPENDIX A: Market Resources

All market resources are located on the Leading in LA project site here and provided to the Energy Commission in the final package of deliverables.

APPENDIX B: Surveys

The owner and installations full questions and responses are Deliverable 3.4 Final Field Demonstration Report.

APPENDIX C: Key Deliverables

1.6 Final Project Report (this report)

2.1 Bench Test at FLEXLAB Test Results

2.2.1 Lab Test Plan

2.2.2 Lab Test Results

2.3.1 Field Test Plan

2.3.2 Site Selection and Technology Customization Report

3.1 Interim Field Demo M&V Report - M&V data plan details

3.2-3.3 Interim Report on INTER System Design and Installation - Energy and IEQ

3.4 Final Field Demonstration Report

4.1 Market Analysis

4.2 INTER Installation Guide and Market-Facing Guide (Getting Control of Comfort and Energy)

4.2 Site and Technology Case Studies

4.3 Policy and Program Recommendations Report

6.1-2 Project Fact Sheets

6.3 Package of all Presentation and Publication Materials

6.4 Technology Transfer Plan

6.5 Final Technology Transfer Report