DE-EE0008188 ISOP

Final Technical Report

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December 2019

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1 Acknowledgment

This material is based upon work supported by the Department of Energy's Office of Energy Efficiency and Renewable Energy Buildings Technologies Office, under Award Number DE-EE0008188.

2 Disclaimer

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3 Executive Summary

The goal of this project was to demonstrate technical feasibility of an integrated approach for deep energy retrofits by packaging innovative technologies with smart communicating controls that represent the next generation of energy efficiency. The integrated solutions for optimized performance (ISOP) package integrates (i) advanced lighting and plug load controls; (ii) intelligent daylight harvesting through automated self-powered shades and window films; (iii) advanced HVAC controls sequences (ASHRAE Guideline (GDL) 36); and (iv) fault detection and diagnosis (FDD) and continuous commissioning (CCx) using advanced analytics. These technologies address energy use across multiple building end uses that represent more than 60% of the energy consumption in all commercial buildings.

The project was structured to be implemented over three budget periods:

- Budget Period 1 scope included site selection, project design, site-specific customization of technology packages, procurement of technologies, initiation of installation of technologies, the development of a measurement and verification plan and collection of pre-retrofit data collection. The first year go/no-go decision was based on securing host sites representing 250,000 sq. ft. of occupied operational spaces, savings analysis, technology procurement and initiation of installation.
- Budget Period 2 planned to complete technology installations and initiate data collection of post-retrofit performance data. The second year go/no-go was to be the completion of technology installations and commissioning, metering and data collecting to support the requirements laid out in site specific M&V plans.
- Budget Period 3 planned to collect and analyze post-retrofit performance data and provide data and reporting to support energy efficiency rebate programs.

After the team completed activities planned for Budget Period 1, the team reached a Go/No-Go Decision Point. At that point, TRC recommended that DOE discontinue the project without prejudice due to challenges with securing demonstration sites to meet the full 250,000 sf of occupied operational spaces and DOE concurred.

In Budget Period 1, the TRC team developed criteria to recruit and evaluate potential demonstration host sites. TRC worked with Princeton University, the project demonstration partner, to identify buildings on their campus as potential candidates for the demonstration. Following the selection of demonstration sites, the TRC team customized energy technology packages according to the needs and characteristics of each site. TRC defined technology specifications, identified vendors, and conducted analysis to estimate energy and cost savings potential. The project team then developed schedules for technology procurement processes and scheduled for installation at all selected demonstration sites. The project team worked with Princeton University and DOE to develop an approach to verify energy savings achieved through measurement and verification (M&V) 2.0 methods. Princeton University initiated open bids to procure the necessary materials and installation contractors. Bid results came back higher than estimates due to a couple of factors – lack of familiarity of the bidders with the proposed technologies and lack of local trained installers to execute the installation of these new measures. Due to the higher bids, projects no longer met the internal cost-effectiveness criteria used by Princeton to proceed with procurement of the full suite of technologies as proposed in ISOP. Princeton had already procured parts of the ISOP package as part of a campus-wide initiative for FDD and lighting retrofits, but with the higher costs for other ISOP components, Princeton could no longer commit to the full ISOP package on the selected sites. Based on this, the team reached the Go/No-Go decision point, where they decided not to proceed with the project. Princeton is separately installing portions of the ISOP package where they individually meet Princeton's payback criteria but on a different schedule than would have been needed for the DOE ISOP project.

The team has learned several lessons from project progress in the first budget period. The team will utilize these lessons in future projects, as should any team which proceeds with a project around the ISOP technology. The first lesson is that more information about the proposed sites is required earlier in the process (perhaps even at the proposal stage) in order to have a successful demonstration. Technical details not evident earlier in the process (such as the TLED limitations for ALCS) can derail project execution. The second lesson is that pricing of emerging technologies is highly variable due to lack of familiarity of local installers and distributor with the proposed technologies as well as alternate bids using products they were more familiar with, but that cost more than the ones proposed by TRC. Finally, the last major lesson is that the host site's internal project criteria is of critical importance. Based on these higher installed costs and lack of an informed installer base for the products proposed for this project, the project does not meet Princeton's simple payback goals of five years.

4 Project Overview

4.1 Project Goals and Objectives

The project goal was to demonstrate technical feasibility of an integrated approach for deep energy retrofits by packaging innovative technologies with smart communicating controls that represent the next generation of energy efficiency. The integrated solutions for optimized performance (ISOP) package integrates (i) advanced lighting and plug load controls; (ii) intelligent daylight harvesting through automated self-powered shades and window films; (iii) advanced HVAC controls sequences (ASHRAE Guideline (GDL) 36); and (iv) fault detection and diagnosis (FDD) and continuous commissioning (CCx) using advanced analytics. These technologies address energy use across multiple building end uses that represent more than 60% of the energy consumption in all commercial buildings.

The project objectives were: (1) to validate in sites representing 250,000 sq. ft. of occupied, operational building space that ISOP technology packages that combine two or more advanced technologies spanning lighting, fenestration, and heating, ventilation, and air conditioning (HVAC) technologies can produce an estimated 756 Tbtu/year in national energy savings when installed in contiguous spaces in all education, office, warehouse, lodging, healthcare, public safety buildings across the United States; and (2) to develop technology data and knowledge transfer vehicles to support the roll out of a utility rebate program in New Jersey. The TRC team planned to do this with the ISOP package. Each demonstration site was to integrate at least two measures and demonstrate savings through measurement and verification (M&V) 2.0 protocols. The TRC team was to deliver this project in partnership with several universities and utilities partners in New Jersey and a network of technology.

4.2 Technical Scope Summary

The three-year project sought to focus on the testing and validation of energy savings, cost and other performance factors associated with advanced ISOP technology packages that integrate solutions across lighting, fenestration and HVAC end uses, and together represent more than 60% of the energy consumption in commercial buildings.

The project was structured to be implemented over three budget periods:

- Budget Period 1 scope included site selection, project design, site-specific customization of technology packages, procurement of technologies, initiation of installation of technologies, the development of a measurement and verification plan and collection of pre-retrofit data collection. The first year go/no-go decision was based on securing host sites representing 250,000 sq. ft. of occupied operational spaces, savings analysis, technology procurement and initiation of installation.
- Budget Period 2 planned to complete technology installations and initiate data collection of post-retrofit performance data. The second year go/no-go was to be the completion of technology installations and commissioning, metering and data collecting to support the requirements laid out in site specific M&V plans.
- Budget Period 3 planned to collect and analyze post-retrofit performance data and provide data and reporting to support energy efficiency rebate programs.

A summary of the technologies and integration pathways in the ISOP package are depicted in Figure 1 and are described below.

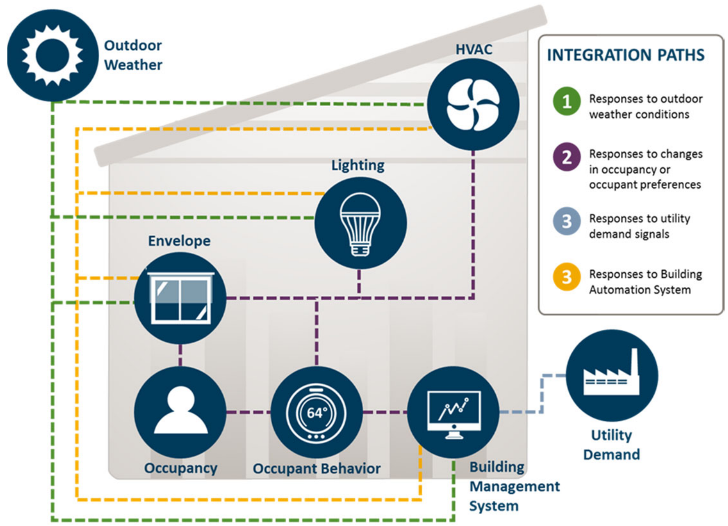

Figure 1. ISOP Technologies and Integration Paths

Advanced Lighting Controls and Plug Load Controls: Internet of Things (IoT) architecture will network LED fixtures and smart sensors to an analytics platform to optimize lighting and plug load consumption in real-time. Controls technologies include luminaire-level occupancy sensing, daylight sensing, time-dependent controls scheduling, and occupancy-based plug load controls integrated with HVAC systems and demand response networks.

Intelligent Daylight Harvesting and Solar Control: The system unifies daylight harvesting, glare control and intelligent controls. Concave louvers track solar patterns and direct diffused daylight deep into the space; PVC free shade fabric provides glare reduction; and choice of controls that allow the system to be individually controlled, controlled as a set, or remote and timer controlled. Other features include PV harvesting for charging Lithium-ion batters, integration with interior lighting operations and the BAS system. Illuminate will be integrated with window films to optimize the heat gain and loss through windows.

Advanced HVAC controls sequences: Implementation of best-in-class sequences of operation- i.e. ASHRAE GDL36 will reduce implementation costs and risk of errors inherent in the current practice; and enable optimal building performance through integration and communication between technologies.

HVAC Fault Detection and Diagnostics (FDD) and Continuous Commissioning: This system will provide effective continuous commissioning to improve operations by diagnosing system problems and poor performance and eliminate operational energy waste. The system will integrate enterprise data from multiple control, monitoring, and metering systems and summarize the data for effective visualization and ease of decision-making.

4.3 Project Team

The project team is shown in Figure 2. TRC was the deployment lead. The New Jersey Institute of Technology (NJIT) was the marketing and outreach partner and was to lead the market transformation and technology transfer activities. The New Jersey Board of Public Utilities (NJBPU) was a programmatic collaborator. Princeton University was a demonstration partner. There were several technology partners, including Enlighted Inc., Lutron, Rollease Acmeda, Automated Logic, Siemens, and Facility Dynamics.

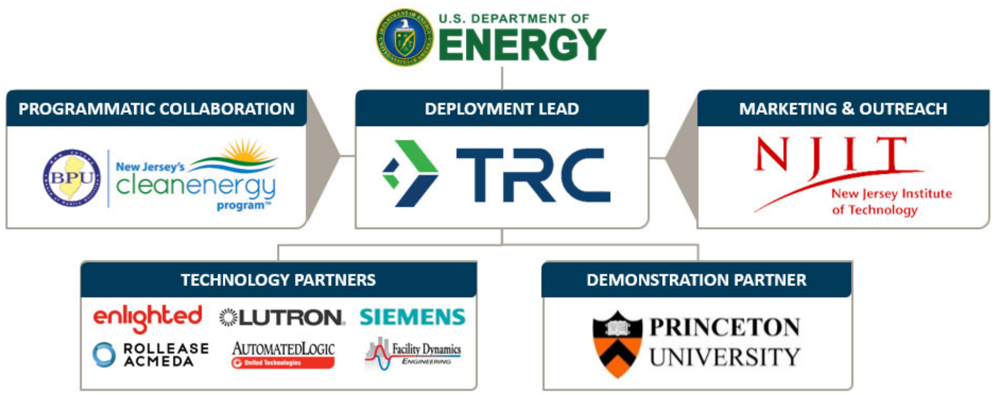

Figure 2. TRC Project Team

5 Project Status

The team completed the first of the three years planned for this project. At the completion of the first year, the team reached the Budget Period 1 Go/No-Go Decision Point. Per the Statement of Project Objectives (SOPO), the Go/No Go decision was based on the following criteria being met: (1) Deliverables have been met; (2) TRC team has commitments from host sites representing 250,000 sq. ft.; (3) TRC team has developed a savings analysis report to identify the packages that will save the most energy and that meets the project objectives; (4) TRC team has developed a ISOP technology procurement and installation schedule that meets the overall project timelines; and (5) Field installation has been initiated according to the installation schedule.

All criteria were met with the exception of criteria 2. The TRC team was not able to attain commitments from host sites representing 250,000 sq. ft. of demonstration. In Budget Period 1, the TRC team developed criteria to recruit and evaluate potential demonstration host sites. TRC worked with Princeton University, the project demonstration partner, to identify buildings on their campus as potential candidates for the demonstration. Following the selection of demonstration sites, the TRC team customized energy technology packages according to the needs and characteristics of each site. TRC defined technology specifications, identified vendors, and conducted analysis to estimate energy and cost savings potential. The project team then developed schedules for technology procurement processes and scheduled for installation at all selected demonstration sites. The project team worked with Princeton University and DOE to develop an approach to verify energy savings achieved through measurement and verification (M&V) 2.0 methods. Princeton University initiated open bids to procure the necessary materials and installation contractors. Bid results came back higher than estimates due to a couple of factors – lack of familiarity of the bidders with the proposed technologies and lack of local trained installers to execute the installation of these new measures. Due to the higher bids, projects no longer met the internal cost-effectiveness criteria used by Princeton to proceed with procurement of the full suite of technologies as proposed in ISOP. Princeton had already procured parts of the ISOP package as part of a campus-wide initiative for FDD and lighting retrofits, but with the higher costs for other ISOP components, Princeton could no longer commit to the full ISOP package on the selected sites.

Because the TRC team had not satisfied the Budget Period 1 Go/No-Go Criteria, the TRC team recommended that DOE discontinue the 8188 ISOP Project without prejudice and DOE concurred. Princeton is separately installing portions of the ISOP package where they individually meet Princeton’s payback criteria but on a different schedule than would have been needed for the DOE ISOP project and outside of the DOE ISOP project.

6 Project Progress

This section describes TRC team progress made during Budget Period 1.

6.1 Project Selection

The TRC team developed criteria to recruit and evaluate potential demonstration host sites. TRC worked with Princeton University to identify buildings on their campus as potential candidates for the demonstration. Facility personnel at Princeton took a list of required and preferred criteria and matched it up against their building stock to short list a set of potential buildings. Princeton personnel provided the TRC team with basic information on each of the candidate buildings, including building size, age, existing metering infrastructure, and mechanical system types. Lastly, the TRC team narrowed down the set of candidate buildings by prioritizing buildings which had stable operations and had different occupancy types and vintages.

6.1.1 Site Selection Criteria

The ideal test sites were two to three buildings from a campus of buildings, totaling a minimum of 250,000 conditioned and occupied square feet, that met the characteristics described below.

Step 1: Facility personnel identified initial candidates using the checklist below. For each candidate building, they reviewed this checklist and excluded any buildings that lacked any of the "required" characteristics.

Priority Level	Characteristic	Check Here if the Building Has this Characteristic
Required	Buy-in from key stakeholders: finance, sustainability, energy, and building operation (already agreed)	☒
Required	Building or portfolio-level point of contact with willingness and knowledge to provide evaluation information regarding occupant/tenant and energy management impacts, and utility tariff information	☐
Required	No plans for other renovations, retrofits, or major occupancy changes during the full study period.	☐
Required	Floor area is ≥ than 50,000 ft^2 for each building	☐
Required	Building includes spaces similar to office, classrooms, cafeteria, dormitories	
Required	Presence of building automation system (BAS) with interoperable communication protocol (e.g., BACnet)	☐

Priority Level	Characteristic	Check Here if the Building Has this Characteristic
Required	Monthly whole building gas/steam use, electric use, and peak demand at the building level	☐
Required	Good documentation of as-built conditions such as drawings, design documents, especially the electrical and mechanical riser diagrams	☐
Required	Daylighting potential, with direct sunlight exposure on some facades, minimum preferred window-to-wall ratio of 30%, and perimeter daylit zones allocated to occupied spaces	☐
Strongly Preferred	Presence of interval whole-building metering	☐
Strongly Preferred	Participation in Local Government Energy Audit (LGEA) program	☐
Strongly Preferred	Key point person for data administration and business process integration	☐
Strongly Preferred	Existing retrofit plans, with allocated budget, within established project timeline (installation period between September 2018 and August 2019).	☐
Strongly Preferred	Presence of sub-metering of energy end uses or building spaces	☐
Strongly Preferred	Stable occupancy, operations, and internal loads during the full demonstration period (before and after technology demonstration)	☐
Strongly Preferred	No unusual load types or unique characteristics that cannot be transferred to the larger market (e.g., labs, theatre, etc.), or unusual/unique load data can be easily separated from the rest of the building	☐

Step 2: For each initial candidate site, personnel familiar with the buildings provided the following information.

Primary Contact	Response
Name	
Organization	

Phone number	
Email	

Building Name:	
General Building Information	**Response**
Address	
Building Vintage (year constructed or last major renovation)	
Major space use types present in building, e.g. offices, hospital, hotel, high education, etc.	
Conditioned Square Footage	
History (year and scope) of major renovations/retrofits/retro-commissioning	
In-house O&M staff, contracted services, or both	
In-house IT staff or outsource	
Describe typical occupancy	
Occupancy variation, historic and future	
Describe daylighting conditions (façade orientation, window-to-wall ratio, occupancy of perimeter zones, space types, etc.)	
Building Data Information	**Response**
Available utility billing data (electric, steam, natural gas, and/or other fuels.), historic data range (minimum data required for the past one year, preferred to have three past years of data)	
Available whole building interval meter data (electric, steam, natural gas, and/or other fuels), historic data range (***please send us one year of historical interval data, if available***)	

Available submeter data (electric, steam, natural gas, and/or other fuels.), historic data range	
Available building automation system data, historic data range (e.g. BAS trends, flags)	
Available construction drawings for all disciplines (preferably as-built drawings)	
Available space planning drawings, including department locations, furniture layouts, etc., as applicable	
Building Systems	**Response**
Building automation system make and model	
Automated lighting control system (if available)	
Computerized maintenance management system (if available)	
Are HVAC control sequences documented? (Yes/No)	
Any other software tool used for building operation	

Step 3: The TRC team considered the following points during the final down-selection.

In determining the final two to three demonstration sites, the TRC team considered the following attributes:

- Alignment with project timeline, requirements, objectives, and budget
- Mix of occupancy types
- Mix of building vintages (to the extent possible)
- Stability of occupancy, operations, and internal loads during the demonstration period

6.1.2 Potential Demonstration Sites

Utilizing the process outlined above, TRC and Princeton University worked together to identify six buildings, totaling 478,000 square feet of floor area, that could serve as potential demonstration sites. Princeton University nominally committed to conducting the demonstration in these buildings and provided a letter expressing this commitment.

6.2 Project Design

Following the selection of demonstration sites, the TRC team customized energy technology packages according to the needs and characteristics of each site and ensured installation of a minimum of two or more of the technologies at each site. TRC defined technology specifications, identified vendors, and conducted analysis to estimate energy and cost savings potential.

The following sections describe the measure selection process, the measure selection criteria, and the resulting building specific measure recommendations that TRC determined.

6.2.1 ISOP Measure Selection Process

Princeton University has a campus central plant, which provides chilled water and steam to buildings on campus, including to all of the potential demonstration sites. Princeton University already meters and stores electricity use, chilled water use, and steam use by building at 10-minute intervals for each building on campus. Data from the past four years was reviewed by the TRC team.

Through the New Jersey Clean Energy Program, Princeton University was eligible for Local Government Energy Audits (LGEA) at many of their older buildings. The LGEA audits provided TRC with lighting inventories for each building, which includes fixture wattage, fixture counts, and estimated annual hours of operation (based on space type). Data collected through these audits helped provide an estimated breakdown of building electricity use by end-use category.

In newer buildings, complete architectural, mechanical, and lighting plans were available and were reviewed for each potential demonstration site. In many cases the information gathered in the plans was supplementary to that provided by the LGEA. Where available, the team also reviewed the building automation system (BAS).

The TRC team went onsite to Princeton University's campus twice to assess the base building conditions in potential demonstration sites. While onsite, the team assessed HVAC and lighting conditions that went beyond those found in the above sources. For example, in the first site visit the team noted a significant amount of glare in the heavily-glazed library in Friend Center.

Feasibility of each measure was discussed with Princeton staff. Princeton's Facilities division has separate groups for the University Architect, Operations, Office of the Vice President, Engineering and Campus Energy, Finance and Administrative Services, Office of Capital Projects, Office of Sustainability.[1] The team's primary communications was through an Energy Project Engineer with the Engineering and Campus Energy Group, with support from other groups such as the University Architect and Capital Projects.

6.2.2 ISOP Measure Selection Criterion

Advanced Lighting, Plug Load Management, and Sensors Integrated with HVAC Controls

The proposed demonstration sites had existing Lutron lighting systems with Lutron lighting control panels capable of handling the additional controls and capabilities envisioned for ISOP.

[1] https://facilities.princeton.edu/about-us/org-charts

High efficiency lighting systems in combination with an advanced lighting control system (ALCS) provide the most energy savings potential for existing buildings by maximizing both the connected load and total effective full time equivalent (FTE) use of the lighting throughout the year, so measures that attempt to accomplish this are considered most favorably.

In existing buildings, there are many mitigating factors that must be considered when making measure choices, and the cost effectiveness must be considered as a primary factor. In the Princeton buildings, all had been retrofitted recently with tubular LED (TLED) lamps which mostly utilize the existing fluorescent ballasts. While TLED lamps save energy compared to baseline due to their low wattage and the ability to work with existing ballasts, they lack the capability to take advantage of ALCS features such as daylight sensing, task and institutional tuning and dimming.

Due to this limitation, the best opportunity for lighting was to add controls to select areas in the demonstration sites to reduce hours of use (HOU) in the lighting system due to occupancy fluctuations or the inclusion of daylighting to reduce the need for electric lighting during the daytime. This required selecting areas of the building with high daylighting potential and making lighting and controls modifications – including replacing TLEDs with controllable LEDs – to capitalize on the opportunity.

Daylight Harvesting through Automated Self-Powered Shades and Window Films

Daylighting is beneficial for several reasons, including energy savings but also occupant comfort and connection to the outdoors that many people find desirable. However, daylighting must be controlled effectively because it often has the risk of causing discomfort or glare if too much direct daylight is permitted into a space in the wrong manner.

Daylighting measures first and foremost must ensure glare control while still permitting adequate daylighting penetration into the space to reduce the perimeter lighting zones to be reduced or turned off. Favorable building and window circumstances will permit deeper daylight penetration and higher energy savings.

The blind/shade combination proposed for ISOP enable good daylight redirection onto the ceiling in the perimeter zone so that the lighting system can be dimmed back or turned off. The electric lighting system would need to be modified to enable the lighting to react most directly in the perimeter zones without compromising the lighting deeper into the building. Thus, for this measure to work as intended, the ALCS upgrade discussed above would be necessary.

HVAC Controls Upgrade and Advanced Control Sequences (ASHRAE Guideline 36)

Guideline 36, developed by the American Society for Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), provides “best-in-class” sequences of operation for heating, ventilating, and air-conditioning (HVAC) systems that are intended to maximize HVAC system energy efficiency and performance, provide control stability, and allow for real-time fault detection and diagnostics. The current HVAC system types that Guideline 36 covers are limited to air-side variable air volume (VAV) reheat HVAC systems, including multi-zone air handling units, single-zone air handling units, and dual fan dual duct air handling units.

The first step was to confirm that the candidate building HVAC systems are covered by Guideline 36. The next step was to determine if the existing building automation system (BAS) infrastructure was capable of being re-programmed with Guideline 36 sequences, or if a control hardware upgrade might be required.

Princeton has a legacy of Siemens and Automated Logic (ALC) BAS systems and several projects in the works to update exiting BAS or replace with newer generation systems. An ALC system with zone controllers installed in the last 5-10 years was deemed to be capable of running Guideline 36. Siemens DXR zone controllers were deemed to be capable of running Guideline 36. Older controls could be upgraded but at higher costs and thus were not recommended.

The measure was subdivided into two measures based upon the condition of the existing BAS.

GLD36 Hardware + Software Retrofit: If the existing BAS was not capable of doing GDL36, hardware upgrades at both the system level and zone level is necessary. Once the hardware is upgraded, the software would need to be reprogrammed to implement GDL36 sequences of operation. This measure applies to all VAV reheat systems within the host sites.

GLD36 Software-only Retrofit: If the existing BAS could do GDL36, the only new hardware required may be some sensors. The software would need to be reprogrammed to implement GDL36 sequences of operation. This measure applies to all VAV reheat systems within the host sites.

Fault Detection and Diagnostics (FDD) and Continuous Commissioning (CCx) using Advanced Analytics

Facility Dynamics Engineering (FDE) Performance And Continuous Re-commissioning Analysis Tool (PACRAT™) is a software that provides FDD and CCx to buildings through advanced analytics. The PACRAT™ software accepts data from BAS, meters, and/or data loggers. Princeton had been working with Facility Dynamics to rollout PACRAT™ software across the campus including the proposed sites.

For buildings where Guideline 36 was not a feasible measure, TRC recommended that the FDD and CCx solution through PACRAT™ software be implemented regardless to identify HVAC savings opportunities as opposed to the usual RCx field audit-based solutions.

While FDD tools detect and diagnose faults in HVAC systems, an FDD tool only saves energy if corrective action is taken on the faults. Most FDD tools on the market today do not provide definitive, actionable steps that a building operator could take. Most FDD tools require an experienced person to interpret the results and perform a corrective action. The corrective actions are often thought of as retro-commissioning (RCx) measures, and span maintenance steps and controls optimization steps. For ISOP, the PACRAT™ software and the associated support to be provided by FDE was deemed to be the right combination of software and engineering support necessary to implement FDD and CCx measures.

6.2.3 Building Specific Measure Recommendations

A summary of the demonstration sites and the measures selected are given in the table below.

Building Data			Recommended Measures	
Name	**Size**	**Age**	**HVAC**	**Lighting + Envelope**
Friend Center	70,700 sqft	2001	G36 hardware + software retrofit; RCx measures leveraging PACRAT	ALCS in all spaces. Automated shades in library spaces
Computer Science	57,000 sqft	1989	RCx measures leveraging PACRAT	ALCS in all spaces. Automated shades in lobby area and select other spaces
New South	57,600 sqft	1965	RCx measures leveraging PACRAT	ALCS in all spaces. Automated shades in all perimeter spaces
Sherrerd Hall	46,600 sqft	2008	G36 software-only retrofit; RCx measures leveraging PACRAT	ALCS in all spaces
Lewis Library	87,000 sqft	2008	G36 hardware + software retrofit; RCx measures leveraging PACRAT	ALCS in all spaces. Automated shades in library spaces

6.3 Technology Procurement

The project team developed schedules and processes for technology procurement and schedules for installation at all selected demonstration sites.

6.3.1 Vendors and Products

For each technology in the ISOP package, Princeton would decide whether to utilize vendors that were already performing work on campus, or conduct an open bid to solicit other vendors. To assist Princeton in making this determination, TRC prepared a list of hardware and software vendors that Princeton could consider for each technology, though Princeton was not confined to this list and could conduct an open bid process and choose whichever vendor they wished for any of the technologies. This was a necessity due to the procurement rules for Princeton that require an open, transparent bidding process and justifications for why sole source awards are necessary if an open bid was not feasible.

6.3.2 Contractors to Perform Work

In order to get the technologies installed, Princeton would hire contractors to perform work at the demonstration sites, as detailed in the subsections below. Princeton would decide whether to utilize contractors that are already performing work on campus or conduct an open bid to solicit other contractors.

Technology	Vendor (Product)	Project Technology Partner?	Additional Considerations
FDD	Facility Dynamics Engineering (FDE)	Yes	FDE's PACRAT already installed in > 60 buildings on campus, including Friend Center, Computer Science, and Lewis Library
BAS	Siemens	Yes	Buildings with existing Siemens BAS (vintage): Friend Center (2004), Computer Science (1987), Lewis Science Library (2008)
	ALC	Yes	Buildings with existing ALC BAS (vintage): New South (2016), Sherrerd Hall (2008)
ALCS	Lutron	Yes	Lutron systems currently exist in multiple buildings
Automated shades	Rollease	Yes	Wireless solution does not require additional wiring to each resulting in less cost.
	Lutron	Yes	Lutron's alternative to the Rollease product work with current Lutron controls onsite.

6.3.3 Workflow by Measure

The subsections below detail the proposed workflow by each measure, including tasks required to install the system, party required for each task, how the costs of the task will be covered, and any additional notes are listed.

RCx Measures Leveraging PACRAT

Task	Party to perform	Cost Coverage
Write functional specifications for work	TRC (lead) and Princeton	DOE grant, TRC cost-share, Princeton cost-share
Develop detailed schedules for technology procurement and installation	TRC and Princeton	DOE grant, TRC cost-share, Princeton cost-share
Select contractors and vendors	Princeton	Princeton cost-share
Procure PACRAT	FDE	Princeton existing contract
Install and configure PACRAT	FDE	Princeton existing contract
Utilize PACRAT to identify Maintenance Measures and Controls Measures	FDE or Identify through Open Bid	Expansion of existing FDE contract or new contract
Make measure actionable	FDE or Identify through Open Bid	Princeton cost-share
Take corrective action on Maintenance Measures	Princeton	Princeton Maintenance budget
Take corrective action on Controls Measures (programming-only changes)	FDE or Identify through Open Bid	Princeton cost-share

GDL36 Hardware and Software Retrofit and Software-only Retrofit

Task	Party to perform	Cost Coverage
Write functional specifications for work	TRC (lead) and Princeton	DOE grant & TRC cost-share
Develop detailed schedules for technology procurement and installation	TRC and Princeton	DOE grant, TRC cost-share, Princeton cost-share
Select contractors and vendors	Princeton	Princeton cost-share
Upgrade building and AHU-level hardware*	Local representative of existing controls system (Siemens or ALC)	Princeton planned upgrade
Upgrade zone-level hardware*	Local representative of existing controls system (Siemens or ALC)	Expansion of Princeton planned upgrade
Revise programming	FDE or Identify through Open Bid	Princeton cost-share
Test and commission	FDE or Identify through Open Bid	Princeton cost-share

*Not needed for software-only retrofit

ALCS

Task	Party to perform	Cost Coverage
Write functional specifications for work	TRC (lead) and Princeton	DOE grant & TRC cost-share
Develop detailed schedules for technology procurement and installation	TRC and Princeton	DOE grant, TRC cost-share, Princeton cost-share
Select contractors and vendors	Princeton	Princeton cost-share
Install system	Lutron or Identify through Open Bid	Princeton cost-share
Test and commission	Lutron or Identify through Open Bid	Princeton cost-share

Automated shades and/or window film

Task	Party to perform	Cost Coverage
Write functional specifications for work*	TRC (lead) and Princeton	DOE grant & TRC cost-share
Develop detailed schedules for technology procurement and installation	TRC and Princeton	DOE grant, TRC cost-share, Princeton cost-share
Select contractors and vendors	Princeton	Princeton cost-share
Install system	Lutron or Identify through Open Bid	Princeton cost-share
Test and commission	Lutron or Identify through Open Bid	Princeton cost-share

*Princeton's campus architect shall be consulted

6.3.4 Schedule for Technology Procurement and Installation

Princeton University had already installed FDD at three of the demonstration sites. For the remaining buildings and the remaining technologies, the TRC team had planned that Princeton University procure and install the technologies in January through April of 2019. This step did not occur with the planned project schedule for the reasons described in section 5.

6.4 Measurement and Verification (M&V)

The project team worked with Princeton University and DOE to develop an approach to verify energy savings achieved, as described in the following sections. While the M&V plan was developed and baseline data collected, the full M&V plan was not implemented since the project was not continued past Budget Period 1. The text below outlines the M&V plan developed in Budget Period 1 and what would have been implemented if the proposed installations moved ahead to Budget Period 2.

6.4.1 M&V Objectives & Approach

The primary objective of measurement and verification (M&V) was to quantify energy savings using M&V 2.0 from installed measures at the site (aggregate) level. A secondary objective was, where sufficient data was available, to quantify energy savings at the end-use level. Quantification of energy savings at the end-use level would allow verification that individual measures are working as intended and contributing to the measure package as intended.

Energy and demand savings were to be calculated according to the International Performance Measurement and Verification Protocol (IPMVP), Option C: Whole Building. Under Option C the project team would analyze energy savings using whole-building 15-minute interval meter data provided by the BAS for a minimum of 3-months pre-retrofit and 6 to 12 months post-retrofit. Multiple years of pre-retrofit energy data was available and may be used if the data quality was determined to be sufficient. The length of the post-retrofit data collection period depended on the technology installation schedule. Given that the performance of the ISOP technologies was expected to vary with the season, a minimum of 6 months was needed, with 12 months being desirable.

Analysis was to be performed with LBNL's open-source M&V 2.0 algorithms to analyze and present savings and uncertainty.

6.4.2 Data Collection Sources

Princeton University has a campus central plant, which provides chilled water and steam to buildings on campus, including to all of the demonstration sites. Princeton University already meters and stores electricity use, chilled water use, and steam use by building at 10-minute intervals for each building on campus. Data from the past one-year is available to the team online. Prior data was available to Princeton staff, who provided data to the team upon request. Data was available from 2014 onwards for all potential candidate buildings.

Additionally, through the New Jersey Clean Energy Program, Princeton University was eligible for Local Government Energy Audits (LGEA) at many of their buildings. The audits were conducted on Friend Center, Computer Science, New South, and Sherrerd Hall. Data collected through these audits will be useful, including an estimated breakdown of building electricity use by end-use category.

The ISOP technologies being demonstrated primarily impact lighting energy use and HVAC energy use in each demonstration building. The chilled water and steam provided by the campus central plant to each of the demonstration sites was used exclusively for cooling and heating, respectively. Electricity use at each building was primarily lighting, HVAC, and plug loads. Each demonstration site had a building automation system (BAS), which the team has online access to, and through which numerous trends were available. These trends included fan power by individual fan, which is the primary HVAC electricity user in these demonstration sites. Combining the fan power from the BAS with the metered chilled water and steam would be considered the HVAC energy use. Subtracting the HVAC electricity use from the building electricity use leaves lighting and plug loads. These loads would not be disaggregated further. Assuming no operational changes in the building, any change in non-HVAC electricity use pre-retrofit and post-retrofit may be attributable to lighting energy use.

Because additional metering was not required for load disaggregation, no additional instrumentation was to be added.

6.4.3 Site-Specific Measurement Plan

Site-specific M&V plans were to be developed for each demonstration building. The plans would include the specific measurement methods, measurement schedules, and measurement locations at each building.

6.4.4 Energy Data Analysis Plan

The building-level analysis was a pre-retrofit vs. post-retrofit consumption comparison using M&V 2.0 approach. The M&V 2.0 approach allows accounting for a number of independent variables. At a minimum, the time of week and the outside air drybulb temperatures were considered as independent variables in the analysis. Additional independent variables such as outside air relative humidity, solar radiation, and other outdoor conditions may be used.

As noted above, there are three streams of energy available for each building: electricity, chilled water, and steam. These energy streams may be analyzed independently and may also be combined and analyzed together.

In the M&V2.0 process, the pre-retrofit data is used to establish a baseline. In LBNL's M&V 2.0 tool, the pre-retrofit data can be uploaded in order to conduct a screening analysis. For the screening analysis, the tool generates a model for the baseline and assesses whether or not the pre-retrofit data is suitable to produce accurate savings estimates, based on the assessment of the goodness of fit of baseline models using industry standard metrics. Should the results of the screening analysis show that the building is not a good fit for M&V, then the team will have several options. The first is to review the pre-retrofit data used. There are multiple years of pre-retrofit data across multiple energy streams. If a suitable baseline cannot be established, then the team may choose to delay technology installation in order to collect more pre-retrofit data, or the team may consider not including that building in the demonstration.

Once post-installation data is available, it can be uploaded in the same M&V2.0 tool. The baseline model generated will be used to project baseline energy use in the post-retrofit time period. The predicted baseline model results will be compared to the actual energy usage in the post-retrofit time period, and the difference will be deemed the energy savings.

6.4.5 Occupant Comfort Impacts

To verify that HVAC and lighting energy savings are not achieved at the expense of occupant comfort, the project team proposed to use a combination of occupant surveys and physical measurements to measure IEQ impacts. The team proposed to use the Center for the Built Environment (CBE)’s web-based Occupant Indoor Environmental Quality Survey™ before and after installation to capture occupants’ perception of thermal comfort (including any over-cooling) and perceived indoor air quality in the baseline condition. In some buildings, the project team planned to administer shorter surveys (called “Right Now” surveys) to assess instantaneous occupant comfort and perceived indoor air quality at various points in time. These shorter surveys would enable better correlation with physical measurements, and occupants will receive notification via text or email to fill out the survey in return for monetary incentives. The project team would coordinate with staff at Princeton to administer all surveys.

Where available through the building BAS, measurements of space temperature, carbon dioxide (CO_2), zone minimum airflow rates, air handler outside air intake, and return air relative humidity were planned to be recorded both pre-retrofit and post-retrofit for comparison. The team may limit analysis to select zones, capturing a variety of orientations (facing each cardinal direction), location (interior, exterior), space types (offices, classrooms, and lounges), and HVAC zone sizes (small and large).

Using surveys and BAS data, the project team planned to assess changes in thermal comfort, including changes in over-cooling. The team planned to use BAS trend data from select zones to assess changes in thermal comfort based on number of hours within ASHRAE Standard 55 thermal comfort zone. The project team planned to assess changes in ventilation rates and occupant perceptions of air quality, as well as acoustic comfort. In spaces with an ALCS retrofit, the team planned to assess occupant perception of lighting comfort. The team planned to make such assessments by analyzing the pre-technology installation and post-technology installation data, both measured (for temperature and CO_2) and reported through surveys (for temperature, CO_2, acoustic comfort, and lighting comfort).

6.4.6 Building Operations Impacts

Factors such as installation, operations and maintenance impacts were planned to be included in the demonstration evaluation. The team planned to hold monthly calls with site operations staff to track progress over the duration of the demonstration. These calls would provide information for the team to document site staff's experiences installing and using the DOE ISOP technologies, including ways in which the technology has streamlined their building management processes.

7 Lessons Learned

The team has learned several lessons from project progress in the first budget period. The team will utilize these lessons in future projects, as should any team which proceeds with a project around the ISOP technology.

The first lesson is that more information about the proposed sites is required earlier in the process (perhaps even at the proposal stage) in order to have a successful demonstration. While TRC had insights into the Princeton campus buildings and Princeton has good records, it still took a while to sort the list of potential buildings and identify retrofit measures. This is because there were technical details not evident earlier in the process (such as the TLED limitations for ALCS).

The second lesson is that pricing of emerging technologies is highly variable due to lack of familiarity, and that that even if they are promising, they may not be cost-effective at the time of a given project. The TRC team developed a technology package for each site, which Princeton used to solicit bids from multiple technology vendors. The TRC team estimated energy and energy cost savings based on past projects, review of Princeton's energy consumption and cost rates, and calculated cost-effectiveness. However, the bids Princeton received were higher than expected and resulted in lower cost-effectiveness than expected. Most of this higher cost is due to the lack of familiarity of local installers and distributor with the proposed technologies as well as alternate bids using products they were more familiar with, but that cost more than the ones proposed by TRC.

Finally, the last major lesson is that the host site's internal project criteria is of critical importance. Based on these higher installed costs and lack of an informed installer base for the products proposed for this project, the project does not meet Princeton's simple payback goals of five years. Apart from the higher bids, the longer payback is also due to Princeton's low utility rates ($0.06/kWh) which makes a five-year payback challenging to begin with.

8 Next Steps for ISOP

The DOE ISOP project is not proceeding beyond Budget Period 1 so this section identifies efforts that the TRC team still believes should be undertaken through a separate project funded through DOE or other funding entities.

The team envisions the next steps for the ISOP technology to be centered around three key tasks: field demonstration, performance evaluation, and market transformation. For a new project, the project team should conduct project selection, project design, technology procurement, and M&V planning should occur similarly to what the TRC did with Princeton University, as outlined above. Following those steps, the project team should conduct a field demonstration, performance evaluation, and market transformation, as summarized below.

Task 1: Field Demonstration: The project team should provide technical oversight to host site for installation activities to ensure proper installation of measures, sensors, and controls, and Cx to ensure that controls sequences are incorporated that capture energy savings due to reduced building loads. After the completion of the installations, the project team should work with the contractors to ensure that technologies and controls sequences are implemented per specifications.

Task 2: Performance Analysis: The project team should focus on post-retrofit building performance analysis using the M&V plan and including analysis of whole building energy savings, cost, indoor air quality, comfort and daylighting. The project team should leverage the installed advanced technology solutions for continuous Cx, FDD, and M&V 2.0 to continually analyze the post-retrofit building performance. The project team should use metered whole building and systems-level energy data, cost data (from technology partners), and indoor environmental quality survey results data to analyze post-retrofit performance and understand the potential of scaling up ISOP packages installations in other buildings. The project team should analyze energy and cost savings potential of applying the packages in varying degrees across different quantities, types and sizes of buildings and examine how the economies of scale could change savings and cost effectiveness of the proposed packages.

Task 3: Best Practice Guide and Program Development: The team should develop market transformation pathways such as best practice guide, package roadmaps and utility programs ideation. A best practices guide could provide guidance for other building types identified as viable market segments for applications of the ISOP packages. The guide could also provide guidance to utilities to enable replication of similar technology package through future utility program design and roll out. A technology scalability roadmap could identify the appropriate packages, identify the buildings with the highest savings potential, and provide an implementation strategy for building owners. Lastly, the team could disseminate the outcomes of a utility program design ideation to peer-reviewed journals.