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FINAL PROJECT REPORT

LIGHTING CALIFORNIA'S FUTURE
Retrofit-Integrated Classroom Lighting System (R-ICLS)

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Lighting California's Future: Retrofit-Integrated Classroom Lighting System (R-ICLS) is the final report for the Lighting California's Future project, Contract Number 500-06-035, conducted by Architectural Energy Corporation. Finelite, Inc. and the California Lighting Technology Center at U.C. Davis were the technical leads for this project. The information from this project contributes to PIER's Buildings End-Use Energy Efficiency Program.

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

ABSTRACT

Lighting California's Future is a California Energy Commission Public Interest Energy Research (PIER) program focused on lighting technologies for buildings. One of the technical projects within this program addressed a retrofit version of the existing Integrated Classroom Lighting System and focused on developing and commercializing a more cost effective classroom/ conference room lighting system.

The project team worked with three California schools to develop and install variations of the Retrofit-Integrated Classroom Lighting System product concept in 13 classrooms. Researchers developed Good, Better, and Best classroom lighting system variations and monitored their usage for one complete school year. The varying levels offered different lighting qualities and met varying payback objectives. Monitoring data were compared to pre-existing data on base classrooms to demonstrate energy savings potential for schools using the systems for retrofit projects. Users were surveyed regarding usage of the system to evaluate whether or not the modified system improved the learning environment.

The Good-Recessed, Best-Recessed, and Best-Pendant systems demonstrated in this project resulted in power density reductions of 53 percent, 54 percent, and 79 percent, respectively confirming the energy saving potential and benefits to California ratepayers. The Better-Recessed system did not show energy reductions as anticipated. Teacher surveys showed positive results from the installed Retrofit-Integrated Classroom Lighting Systems.

Keywords: ICLS, integrated classroom lighting system, R-ICLS, retrofit integrated classroom lighting system, lighting controls, energy efficiency, and teacher control switch

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EXECUTIVE SUMMARY

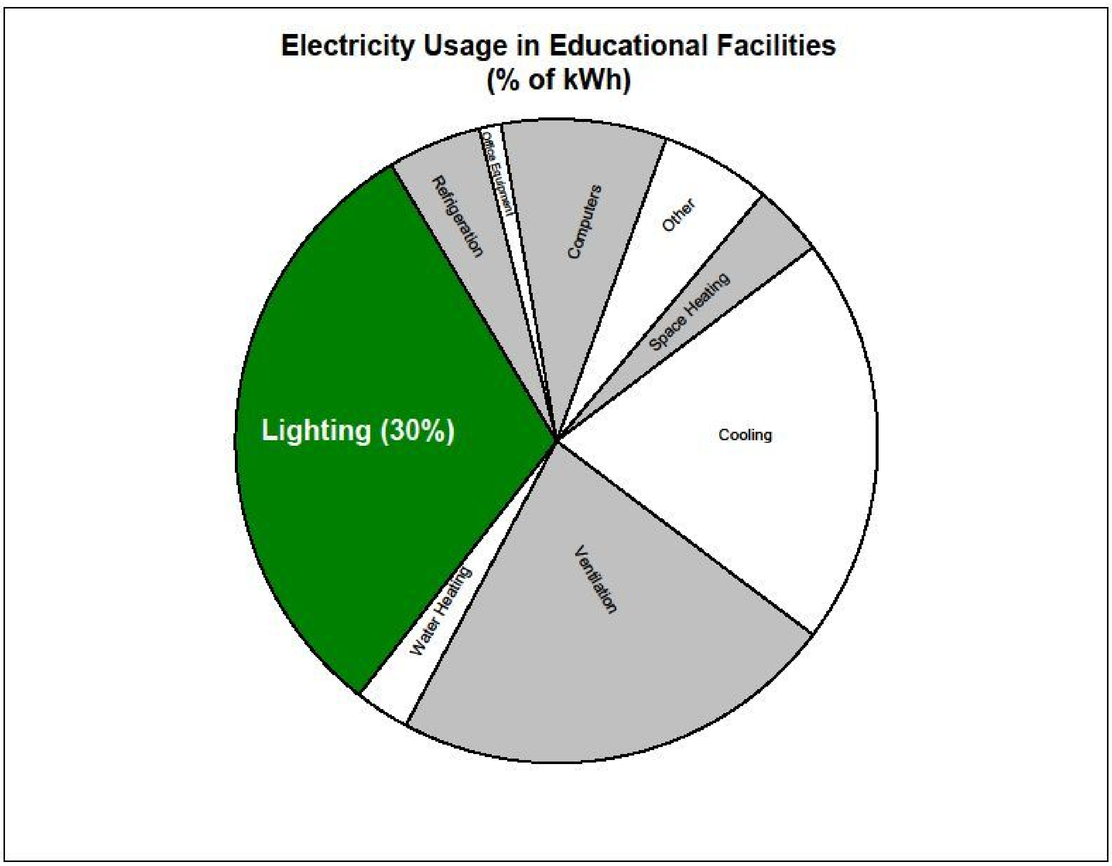
Introduction

Lighting California's Future was a California Energy Commission Public Interest Energy Research (PIER) program focused on lighting technologies for buildings. The program, which began in May 2007, featured nine technical projects and a crosscutting market connection project. One of the nine technical projects was a 2.5-year research project that developed and tested a retrofit version of the existing Integrated Classroom Lighting System to develop a range of cost-effective retrofit solutions. The research team included Finelite, Inc., who provided match funding, and the California Lighting Technology Center at U.C Davis.

Purpose

As seen in Figure 1 below, lighting typically represents 30 percent of the total electricity used in schools. Accordingly, many schools are exploring cost-effective ways to retrofit their electric lighting in classrooms.

Figure 1: Electricity Usage in Schools



The Retrofit Integrated Classroom Lighting System Project, co-funded by Finelite, Inc. and the California Energy Commission's PIER program, developed a range of cost-effective retrofit solutions that meet today's teaching methods. The data indicate that schools should do more than just reduce the lighting load in the classroom.

Project Objectives

The original objectives of this project included the following:

- Document the major opportunities and differences between new construction and retrofit with respect to lighting and control systems for classrooms and the different cost and payback requirements required for each project type. Apply this information to developing "Good," "Better," and "Best" levels of a Retrofit Integrated Classroom Lighting System to reflect different payback levels and different goals with respect to investing in better lighting for tomorrow's teaching needs.
- Research, design, build, and install 13 Retrofit-Integrated Classroom Lighting System demonstration systems as follows:
  - Three "Good" Retrofit Integrated Classroom Lighting Systems targeted at retrofits that need a three-year or better payback based entirely on projected energy savings.
  - Three "Better" Retrofit Integrated Classroom Lighting Systems targeted at retrofits that need a six-year or better payback based entirely on projected energy savings.
  - Three "Best-Recessed" Retrofit Integrated Classroom Lighting Systems targeted at retrofits that can have up to a 10-year payback on energy savings.
  - Four "Best-Pendant" Retrofit Integrated Classroom Lighting System targeted at retrofits that can have up to a 10-year payback on energy savings.
- Use independent researchers to document Retrofit-Integrated Classroom Lighting System lighting performance including light levels, energy savings, teacher preferences, installed costs, and payback periods.
- Create a classroom retrofit guide that will help school districts determine which level of retrofit approach is most appropriate given the nature of their existing classrooms and their payback criteria.

Project Outcomes

The standard lamp/ballast retrofit system yields energy savings. However, it offers no improvement to the lighting performance in the classroom. The project team identified issues and solutions associated with retrofitting typical classroom lighting. The product development effort was guided by the standards for classroom lighting established by the U.S. Green Building Council's Leadership in Energy and Environmental Design and the Collaborative for High Performance Schools.

Finelite and the California Lighting Technology Center surveyed the available technologies to achieve luminaire control within the constraints of the following requirements: 1) eliminate the need to penetrate the ceiling; 2) eliminate the need to run excess electrical conduit or low-voltage dimming lines; 3) controls could not be battery-powered or remotes (not physically mounted to the wall); 4) the system will achieve an audiovisual mode; 5) the system must be robust to accommodate the long life of schools; and 6) the system must not cause interference between classrooms.

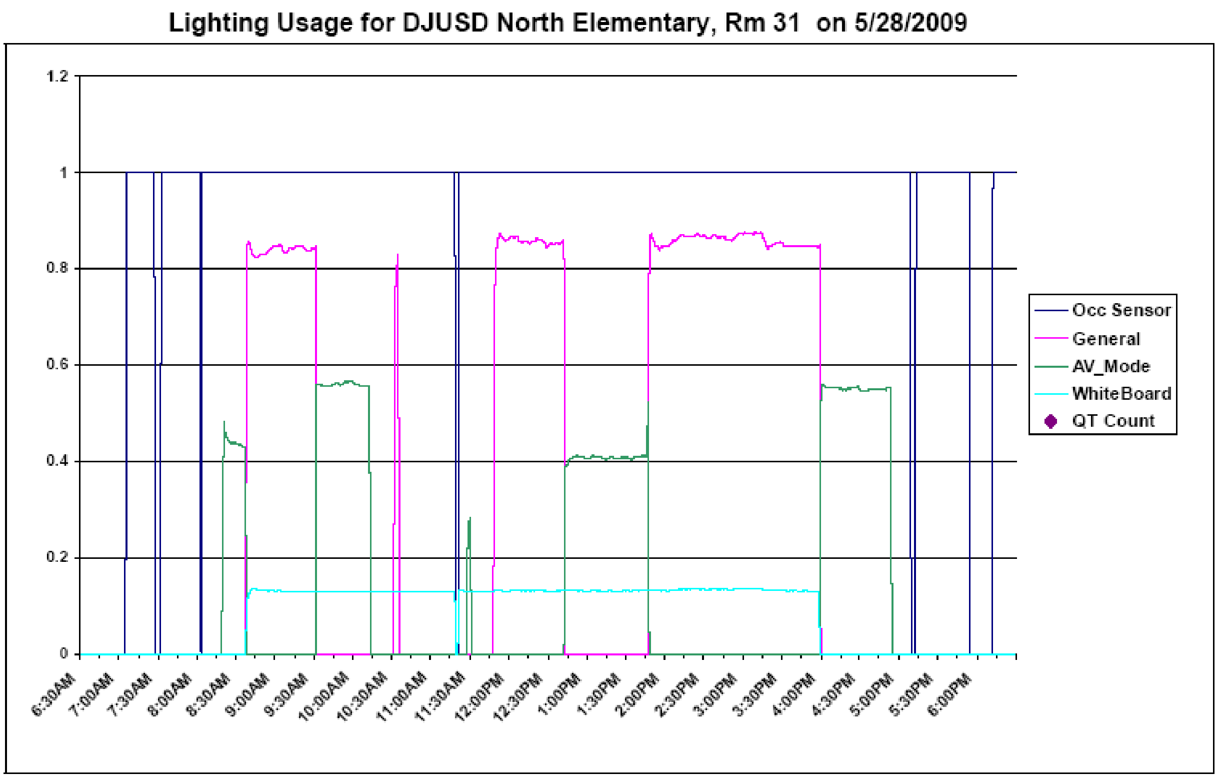
This project developed the following categories of systems to deliver energy savings, improve the lighting quality, address the needs of today's classrooms, and meet varying payback timelines. Each category builds upon the preceding list of components.

- Retrofit Integrated Classroom Lighting System "Good" was developed to bring an audiovisual mode into the classroom environment to meet today's new teaching methods without the need for additional wiring or ceiling supports.
    - Replace lamps and ballasts.
    - Install teacher lighting controls.
    - Install dual technology occupancy sensors.
    - Use existing master on/off controls.
    - Install wireless control center.
- Retrofit Integrated Classroom Lighting System "Better" was developed to do more than deliver an audiovisual mode. Previous studies focused on new construction and major remodels. This system adds whiteboard illumination, which yields higher user preference and reduced energy consumption.
    - Add whiteboard luminaire.
- Retrofit Integrated Classroom Lighting System "Best" provided the highest quality option. In addition to adding A/V mode to the classroom, the Retrofit Integrated Classroom Lighting System "Best" replaced the previously specified luminaires with higher-performing luminaires to deliver even greater quality and energy savings to the classroom.
    - Replace luminaires with high-performance recessed luminaires or high-performing pendant luminaires.

Existing lighting systems were retrofitted in 13 classrooms within three schools in California. Three classrooms were "Good", three were "Better", three were "Best" using recessed luminaires (light fixture installed into a hollow opening in a ceiling), and four were "Best" using pendant luminaires (light fixture that hangs down from a ceiling). Existing conditions were recorded at each site. Installation costs were recorded to capture material and labor costs for each site. A data monitoring system recorded actual usage every minute of every day for a complete teaching year (3.2 million data points). This data provided detailed information on how teachers used the system and what amount of energy was consumed over the school year. Figure 2 shows an example of the lighting usage data obtained during the monitoring period.

Table 1 contains the pre-retrofit and post-retrofit power usage and power density data for each system. The 2008, Title 24 building energy efficiency code specifies the power density for classrooms as 1.1 watts/square foot (W/ ft²) for the Complete Building method and 1.2 W/ ft² for the Area Category method.[1] The Good-Recessed, Best-Recessed, and Best-Pendant systems had power density reductions of 53 percent, 54 percent, and 79 percent, respectively. The pre-retrofit lighting power densities were higher than code at 1.55, 1.92, and 4.26, and the post-retrofit lighting power densities were lower than code at 0.73, 0.89, and 0.88.

Figure 2: Lighting Usage Chart for Davis North Elementary



The Better-Recessed system had a power density increase of 14 percent. The pre-retrofit lighting power density of 1.18 W/ ft² was close to the strictest code level, while the post-retrofit lighting power density of 1.35 W/ ft² did not meet current code. The power density increase is due to: a) the addition of the whiteboard luminaire, b) the fact that not all of the pre-retrofit lamps and ballasts were working, and 3) the dimmable ballasts installed consume slightly more wattage than the electronic T8 ballasts they replaced.

1 The 2008 Title 24 energy efficiency code for new construction in California was in effect at the time of the research.

Table 1: Actual Lighting Power and Lighting Power Densities

School	Davis Senior High	Davis Senior High	North Davis Elementary	Franklin Elementary
System Type	Good-Recessed	Better-Recessed	Best-Recessed	Best-Pendant
Pre-Retrofit Power (W)	1,488	1,062	1,728	3,544
Pre-Retrofit Power Density (W/ ft^2.)	1.55	1.18	1.92	4.26
Post-Retrofit Connected Power (W)	696	1,212	796	735
Post-Retrofit Power Density (W/ ft^2)	0.73	1.35	0.89	0.88
Retrofit Power Savings (%)	53%	-14%	54%	79%

Simple paybacks for the Retrofit-Integrated Classroom Lighting System options were calculated but found to not meet the original goals of the project. The simple payback ranged from 8.9 to 23.6 years for this limited scale retrofit, but costs could be reduced with a larger scale deployment that includes other areas, such as gymnasiums, corridors and offices.[2] The research team identified two key cost criteria required to make lighting retrofits viable for school districts: 1) $2,500 cost per classroom for Retrofit Integrated Classroom Lighting System and 2) $500 energy cost savings.

The research team reviewed luminaires available and determined that it was necessary to develop a new luminaire to deliver the necessary performance at an affordable price. The High Performance Recess product was developed by Finelite during this project.

Teachers were interviewed by researchers and completed questionnaires with respect to the qualitative aspects of the retrofit alternatives. Teachers readily accepted the Retrofit Integrated Classroom Lighting System with an audiovisual mode. The majority of teachers surveyed felt that the Retrofit Integrated Classroom Lighting System was better than the previous system used. No teacher reported that the previous lighting was better than Retrofit Integrated Classroom Lighting System. Teachers surveyed found the lighting comfortable even with lighting levels being reduced and found location and usage of the teacher controls to be convenient.

Finelite developed a classroom retrofit guide as part of this project. The brochure covers the reasons why a high-performance retrofit is important for today's classroom environment, the costs associated with different strategies, and the templates necessary to achieve the results described in this project. The guide provides considerable project data including installation costs, energy savings, and teacher preferences.

2 Detailed cost information can be found in Chapter 9 and in Appendix C.

Conclusions

Existing luminaires in the classroom drive the retrofit decision. Retrofit projects minimize costs by reducing construction labor and materials. The available budget does not accommodate rebuilding space, rewiring, or adding additional ceiling supports. Replacing existing luminaires with those of a similar form ensures that the existing supports and electrical feeds can be used, drastically reducing installation costs. The Retrofit Integrated Classroom Lighting System options address the two most common fixture types used in classrooms: recessed 2x4 and suspended linear fluorescent luminaires.

The project team evaluated three categories of retrofit solutions (Good, Better, and Best). Factoring in utility incentives would make these solutions more viable for a wider range of school districts throughout California.

- Retrofit Integrated Classroom Lighting System "Good" is viable for recessed luminaire retrofit projects. The project evaluated and found the "Good" level was not viable for pendant luminaires as the unique configurations of pendant luminaires would lead to higher than acceptable labor costs to rewire.
- Retrofit Integrated Classroom Lighting System "Better" was not found to be viable for either recessed or pendant classrooms. The inability to change luminaire layouts in the recessed application leads to higher light levels, which decreases the importance of the whiteboard luminaire. The added cost and added power of the whiteboard luminaire also increases the payback timelines beyond acceptable limits. "Better" pendant range is not viable for the same reasons as the "Good".
- Retrofit Integrated Classroom Lighting System "Best" is viable for both recessed and pendant applications. Lighting quality is improved by replacing existing recessed luminaires one-for-one with high performance luminaires, or changing the pendant luminaires and layout. This is a very appealing solution for schools that want to improve lighting quality and energy efficiency at costs significantly below major remodels.

Retrofitting pendant luminaires requires a different strategy than recessed luminaires due to the unique construction and layout of pendant systems. The older design philosophy and luminaire efficiency led to using more luminaires than necessary. Today's luminaires are much more efficient. Two rows of luminaires can now provide what previously took three rows. The wiring of pendant luminaires affects luminaire design making the "Good" and "Better" options not viable. The pendant retrofit decision is either simply replace the lamps with lower wattage T8 lamps or change out the luminaires. Changing luminaire layouts dramatically improves the lighting quality and yields the greatest energy savings. Retrofit Integrated Classroom Lighting System "Best-Pendant" replaced three rows of T12 direct/indirect luminaires with two rows of efficient direct/indirect luminaires.

High-performance retrofit classrooms emphasize an audiovisual mode and teacher controls at the front of the classroom. It is critical for classroom lighting retrofits to give instructors a lighting mode that improves the contrast and effectiveness of audiovisual presentations used to instruct and engage students. The placement of teacher controls is equally important. Controls placed at the front of the classroom provide more teacher control and additional opportunities for energy savings. Missing the opportunity to update the classroom during a retrofit project reduces the overall effectiveness of the classroom for years.

Other conclusions drawn from this project include a strong teacher preference for classroom lighting with audiovisual mode and controls for audiovisual mode located at the front of the classroom. Energy savings can be achieved with excellent user acceptance.

Despite significant power and energy savings, the Retrofit Integrated Classroom Lighting System cost remains prohibitive, with simple paybacks exceeding the typical windows that many school districts need. Labor and materials costs are the two factors that affect cost effectiveness. For material costs, the driving factor in making Retrofit Integrated Classroom Lighting System viable for more districts is reducing the cost of dimming ballasts and wireless controls. When compared to a traditional lamp/ballast retrofit, significant incremental expenses for Retrofit Integrated Classroom Lighting System are for the dimming ballasts and wireless controls.

It also is important to factor in the economy of scale as efficiency gains can be realized in larger projects. If an entire building, school, or district were to be retrofitted, the install cost would be less because the contractor's learning curve and marginal costs would be reduced.

Recommendations

The research team has identified two key cost criteria that must be met to achieve viable paybacks for school districts of 5 years or less: 1) $2,500 labor and material cost per classroom for Retrofit-Integrated Lighting System(R-ICLS) and 2) $500 annual energy cost savings. School retrofits eliminating high lighting power densities or T12 classroom lighting, volume pricing for Retrofit Integrated Classroom Lighting System options, and efficiency labor gains are critical to meeting these cost parameters. Scheduling is an important part of installation cost containment, taking place when schools are not in session.

Retrofitting lighting in additional areas such as corridors and gymnasiums could increase energy savings and allow schools to take advantage of economy of scale and gains in labor efficiency, resulting in shorter payback periods.

The manufacturing partner will continue to evaluate the design and system configuration to develop cost-effective classroom retrofit solutions. The Retrofit Integrated Classroom Lighting System options provide a great visual environment and user flexibility in a system that is environment friendly and meets the requirements of the Leadership in Energy and Environmental Design (LEED®) and California High Performance Schools (CHP).

More demonstrations of the Retrofit Integrated Classroom Lighting System with the above recommended changes would better define viable retrofits.

Commercialization Potential

This project demonstrates that the Retrofit Integrated Classroom Lighting System yields energy savings, has the potential to improve the learning environment, and is preferred by teachers. The wireless technology used to achieve results is easily implemented without the need to run additional ceiling supports or electrical conduit. The labor required to install the system is greater than the traditional lamp/ballast retrofit, and the material costs for the wireless controls and dimming ballasts are still too high to meet the payback requirements for many retrofit applications.

Benefits to California

An estimated 300,000 public K-12 classrooms exist in California with 210,000 rooms that are more than 25 years old. Each school district has the opportunity to drastically reduce the amount of energy consumed in these classrooms while updating these classrooms to accommodate new technology and teaching methodology making them better learning environments. Missing the opportunity to update classroom lighting to high-performance systems today means the learning environment will not be improved for another 20 to 30 years.

Based on 1 percent market penetration and energy savings potential of 20 percent for lighting, electric consumption savings of 4 gigawatt hours and demand savings of 0.8 megawatts could be achieved. Demand savings are dependent on use of the school buildings and classrooms during peak demand periods.

CHAPTER 1: Introduction

Lighting California's Future (LCF) was a $3.7 million California Energy Commission Public Interest Energy Research (PIER) program focused on lighting technologies for buildings. The program, which is managed by Architectural Energy Corporation, featured nine technical projects and a crosscutting market connection project. The program goal was to advance and evaluate energy-efficient, lighting technologies, products, systems, and implementation tools, and bring them to the market for the benefit of California citizens.

The Retrofit-Integrated Classroom Lighting System (R-ICLS) project's goal was to commercialize a cost effective, retrofit specific version of the Integrated Classroom Lighting System (ICLS), which is also a PIER-funded technology and was demonstrated at many University of California (UC) and California State University (CSU) campuses. Through these demonstrations, it was found that installation labor and material cost contributed heavily to long payback periods that are unacceptable in retrofit applications. This product development effort also has been guided by the standards for classroom lighting established by the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) and the Collaborative for High Performance Schools (CHPS).

The research team included Finelite, Inc., who also provided match funding, and the California Lighting Technology Center (CLTC) at U.C. Davis. Key objectives of this project were to develop a classroom lighting system that improves lighting quality, simplifies instructor scene control, and reduces energy demand and consumption. Another objective of this project was to demonstrate the systems in actual classrooms, monitoring and gathering feedback from teachers and students about the quality and functionality of the systems. Finally, the project team hoped to increase the cost effectiveness of the R-ICLS, by optimizing the designs based on lessons learned from the field demonstrations. Equipment and high labor costs are viewed by school decision makers and designers as prohibitive in achieving wider campus specification in retrofit applications. The project team used the development process to identify issues and solutions associated with retrofitting typical classroom lighting.

1.1 Background

The R-ICLS project built upon the existing Integrated Classroom Lighting System, a system developed by Finelite Inc. under Project 4.5 of the PIER Lighting Research Program (LRP) completed in 2005. The research team for the original ICLS Project included architects, engineers, lighting designers, facility managers, project managers, general and electrical contracts, school administrators, and teachers. The primary goals of that project included improved lighting quality, reduced energy consumption (20 percent below Title 24 2005), and addressing the needs of the new teaching methodologies used in high performance classrooms. Additionally, the team sought to develop a system that reduced installation costs to make high performance lighting affordable for all school districts.

In 2005, the classroom lighting design that was recommended by CHPS included 3 rows of indirect/direct luminaires to improve the lighting quality and reduce energy consumption to around 1 W/ft^2 (Watts per square foot). Independent luminaire row control was placed in the standard location by the room entrance. The results from this earlier project include: a) design improved lighting quality with reduced energy consumption; b) design did not address the needs for a mode specifically used for audiovisual (A/V) presentations; c) controls by the door were not used on a frequent enough basis to result in additional energy savings; d) use of traditional wiring methodology did not integrate controls and sensors, which increased the installed cost; ande) use of three luminaire rows also increased the cost to school districts.

The research team for PIER LRP Project 4.5 developed the ICLS using direct/indirect suspended luminaires that incorporated improved optical designs (including a new 96 percent reflective white material), high ballast factor ballasts, and “Super T8” lamps, which enable the classroom to be illuminated with just two luminaire rows, which reduced the cost by one third. The ICLS also incorporated a unique 2-T8/1-T8 luminaire design that enabled the teachers to achieve two simple but effective lighting modes: General Mode (2-T8 lamps per luminaire) and A/V Mode (1-T8 lamp per luminaire).

In A/V Mode, the two outboard indirect lamps were turned off, and the center direct lamp (shielded by a highly reflective optical element) was turned on. This design resulted in benefits to the learning environment and reduced energy consumption. First, the contrast was dramatically improved on A/V screens and interactive whiteboards making them easily visible from all areas of the classroom thus improving their effictiveness. The A/V Mode also provided enough light in the classroom to keep students alert, allowed the teacher to maintain eye contact, and provided enough light on the desks for note taking. The result was an improved learning environment. Second, when teachers changed the lighting to the A/V Mode, energy consumption was cut in half. This reduction resulted in overall energy savings from 30-50 percent. The ICLS also put teacher controls at the front of the classroom, which afforded the teacher easy access to them and increased the likelihood that the teachers would use them to change the learning environment and reduce energy consumption. The ICLS incorporated a plug-and-play structure to tie the luminaires, sensors, and controls in and easy to specify and install system.

The New York State Energy Research and Development Authority (NYSERDA) took the research completed in PIER LRP Project 4.5 and tested the system and the importance of a task specific whiteboard luminaire. The systems were tested in K-12 and university level classrooms. This research demonstrated additional energy savings and unanimous teacher acceptance. The addition of the whiteboard luminaire reduced the ambient illumination levels and improved the ability for all students to read what was written on this vital communication tool. In addition to improving the clarity of written text, the use of the whiteboard luminaire also resulted in another mode: the Focus Mode. Teachers found the ability to place the lights in A/V Mode while turning on the whiteboard luminaire enabled them to focus attention on board work while providing a very calming atmosphere. The research found teachers unanimously prefered the ICLS system to previous systems, and demonstrated an effective energy consumption of just

0.68 Watts/ ft^2 (52 percent below American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) 90.1 2004.

1.2 Project Overview

1.2.1 Project Goals

The goal of this project was to develop cost-effective, retrofit systems that will bring many of the benefits of original ICLS to the retrofit market segment. The ICLS was developed as a result of the PIER LRP Project 4.5 and was primarily focused at the new construction and major remodel segments. The benefits of the R-ICLS included:

- Energy savings for an estimated 300,000 existing California K-12 through university classrooms. R-ICLS will use 20 percent less energy than 2005 Title 24 levels for new classrooms.
- Control to help meet today and tomorrow's teaching technologies.
- Glare-free lighting for general education and A/V requirements that meets or exceeds Illuminating Engineering Society of North America (IESNA)-recommended levels and provides the opportunity for cost-effective daylight harvesting.
- Single-source systems solution where classroom layout, system pricing, installation support and warranty services are all provided from one manufacturer.

A Retrofit Guide to help school staff identify the best retrofit strategy for their school was developed as a result of the R-ICLS project.

1.2.2 Project Objectives

The objectives of this project included the following:

1) Document the major opportunities and differences between new construction and retrofit with respect to lighting and control systems for classrooms and the different cost and payback requirements required for each project type. Use this understanding to develop "Good," "Better," "Best" levels of R-ICLS to reflect different payback levels and different goals with respect to investing in better lighting for tomorrow's teaching needs.
2) Research, design, build, and install 13 R-ICLS demonstration systems as follows:
    a) Three "Good" R-ICLS systems targeted at retrofits that need a 3-year or better payback based entirely on projected energy savings.
    b) Three "Better" R-ICLS systems targeted at retrofits that need a 6-year or better payback based entirely on projected energy savings.
    c) Three "Best-Recessed" R-ICLS systems targeted at retrofits that can have up to a 10-year payback on energy savings. This payback period would reflect a school district's interest in the many benefits associated with more control of better quality lighting in addition to energy savings.

d) Four "Best-Pendant" R-ICLS systems targeted at retrofits that can have up to a 10-year payback on energy savings. This payback period would reflect a school district's interest in the many benefits associated with more control of better quality lighting in addition to energy savings.

3) Use independent researchers to document R-ICLS lighting performance including light levels, energy savings, teacher preferences, installed costs, and payback periods. Document at least six R-ICLS systems for an entire teaching year to document actual energy savings and how teachers use them.

4) Create a Classroom Retrofit Guide that will help school districts find out what level of retrofit approach is most appropriate given the nature of their existing classrooms and their payback criteria.

1.3 Benefits to California

An estimated 300,000 public K-12 classrooms exist in California with 210,000 rooms that are more than 25 years old. The State of California has the opportunity to drastically reduce the amount of energy consumed in these classrooms while updating the rooms to accommodate new technology and teaching methodology creating the opportunity for better learning environments.

The normal classroom ideally suited for a lighting retrofit lighting program will typically have 12 recessed luminaires that generally have between 3-T12 and 4-T12 lamps. Based on one percent market penetration and energy savings potential of 20 percent for lighting, electric consumption savings of 4 gigawatt hours (GWh) and demand savings of 0.8 megawatts (MW) could be achieved. Demand savings are dependent on use of the school buildings and classrooms during peak demand periods.

The ability to update the retrofit classrooms to meet high performance learning standards cannot be stressed enough. Today's classrooms have changed. The way teachers teach has changed. The technology brought into the classroom must have an audiovisual mode that provides proper contrast on projected images while providing enough light for classroom communication. Missing the opportunity to update classroom lighting to high performance systems now would be detrimental. Once lighting systems are configured in a classroom, it can be 20-30 years before the system is updated again due to high installation costs to reconfigure lighting systems.

1.4 Commercialization Potential

This project demonstrates that the R-ICLS yields energy savings, has the potential to improve the learning environment, and is preferred by teachers. The wireless technology used to achieve results is easily implemented without the need to run additional ceiling supports or electrical conduit. The labor required to install the system is greater than the traditional lamp/ballast retrofit, and the material costs for the wireless controls and dimming ballasts are still too high to meet the payback requirements for many retrofit applications.

Retrofit projects should focus on one of two directions. Either de-lamp luminaires and change to more efficient T8 systems or, if the budget can accommodate a major renovation project, then the "Best" solution, which emphasizes use of either high-performance recessed or pendant luminaires, becomes the viable solution with much better lighting quality, teacher controls, and energy savings potential.

1.5 Report Organization

The report reviews the project approach, outcomes, conclusions, and recommendations of the research and is organized as follows:

- Chapter 2 describes the project approach.
- Chapter 3 summarizes how the research team researched the retrofit market.
- Chapter 4 shows the research into available technologies.
- Chapter 5 highlights the different systems developed.
- Chapter 6 highlights the Retrofit Guide.
- Chapter 7 describes the deployment of retrofit systems in classrooms to test the acceptance and energy savings potential.
- Chapter 8 summarizes the market connection activities.
- Chapter 9 and Chapter 10 present the outcomes, conclusions, and recommendations.
- The appendices provide specific details on teacher preference, the retrofit guide, data collection methodology, demonstration installation costs, and specific data for each installation site.

CHAPTER 2:
Project Approach

The main goal of this project was to develop a retrofit system for classroom lighting that improves light quality, simplifies instructor scene control, and reduces energy demand and consumption. The product development process began with LEED and CHPS standards and built upon the success of the original ICLS system.

Since equipment and high labor costs were viewed by school district decision makers and designers as prohibitive in achieving wider campus specification in retrofit applications, the project team used the development process to identify the main issues apparent with typical classroom lighting. Details and supporting sources for these typical conditions are presented first followed by the proposed product specification.

The project team developed solutions to retrofit recessed systems without having to change luminaire layouts or luminaire product types. This design direction is important to minimize installation costs. Classrooms with pre-existing recessed products must be addressed as a recessed retrofit application. In this way, existing supports that run from the luminaire to the ceiling can be used. Similarly, existing electrical feeds can be used, which minimizes the need to run additional electrical conduit. This is important in reducing installed costs as well as providing solutions where ceiling penetration is not economically feasible. Applications where luminaires are to be moved or entirely new product types are to be employed moves the project wholly outside the retrofit application and should be considered only when the school has the funds to complete a major renovation.

The project team developed a solution for pendant-mounted luminaires, which were estimated by the team to be in 25-30 percent of classrooms throughout California. During the research of this product class, it was determined that the uniqueness of the pendant systems – both in design and implementation – drove the design strategy to consider two possibilities. First, simply change out lamps to lower wattage T8 products. This achieves better lighting quality through the use of high performance lamps. It also results in energy savings when changing from poor performing T12 lamps. The second alternative, which was used in this project, was to replace the luminaires in the classroom with new high performance luminaires. Unique luminaire attributes are required to achieve significant savings in the pendant luminaire application.

The project team developed three levels of recessed R-ICLS solutions, hereafter referred to as "Good," "Better," and "Best." The team also developed one pendant solution – "Best-Pendant". Descriptions of each system are provided along with a detailed component review in subsequent sections.

To achieve these goals and objectives, the CLTC and Finelite used the following research methodology:

1) Survey the marketplace and identify major segments in the classroom retrofit market and their particulars and payback requirements.
2) Survey the available technology required to achieve the project goals and objectives. Solutions considered for the project had to be able to be effective in classrooms where above-ceiling access was not possible and extensive rewiring of luminaire systems was not required. Systems also had to be commercially available and tested to ensure they would last the 40+ life of the school.
3) Develop "Good", "Better", and "Best-Recessed" and "Best-Pendant" scenarios to meet specific payback requirements.
4) Work with three schools to install test classrooms for each classroom type.
5) Use an installing contractor to collect pre-installation data including energy consumption, luminaire type, and illumination levels.
6) Install monitoring equipment in two classrooms of each R-ICLS system type (eight classrooms total). Thirteen classrooms were installed with systems, though not all were monitored. Data was monitored 24 hours a day for the entire teaching year.
7) Document system performance, including user surveys to gauge teacher preference, energy loads, and light levels.
8) Use the data to develop a Retrofit Guide for use by school facilities to determine the best solution for their school projects.
9) Produce a final report with findings and supporting documentation.

Key tasks to be accomplished using this approach are summarized in Table 2.

Table 2: Project Tasks

Task 1: Survey the retrofit market
Task 2: Survey luminaires, sensors, controls, and interconnection technologies
Task 3: Develop three levels of R-ICLS
Task 4: Deploy and monitor R-ICLS in classrooms
Task 5: Develop a Classroom Retrofit Guide
Task 6: Produce Final Project Report
Task 7: Project-level market connection activities

CHAPTER 3: Survey the Retrofit Market

California has more than 6.2 million students in public K-12 schools and more than 1.2 million students in public institutes of higher education, with more than 310,000 teachers in the public K-12 system. As of the end of the 2009 school year, about 300,000 public K-12 classrooms[3] existed with an average class size of 25.2 students. Sixty-nine percent of classrooms in use are more than 25 years old. The existing lighting condition in these classrooms tends to be poor, with lighting power densities ranging widely from 1.0 to 4.0 W/ft^2, often far exceeding the ASHRAE maximum of 1.4 W/ft^2. Most existing classrooms in the state could benefit from an R-ICLS solution.

At the same time, “the educational construction market is the largest commercial construction market by value, comprising 27.4 percent of all commercial construction[4]" and alterations or retrofits account for 19 percent of the value of all education related construction projects. California classroom modernization needs are expected to total $2.54 billion in the next 5 years[5].

Though population growth in California continues to decrease, state population continues to grow by approximately one percent yearly, ensuring the necessity of future classroom construction and upgrades.

Funding sources for green infrastructure improvements and general school upgrades can be found through a variety of local, state and federal programs. Proposition 1D in California has $10.4 billion for the repair and modernization of kindergarten to university school facilities. The California Energy Commission’s Bright Schools program provides technical assistance to identify cost-effective energy saving strategies in public K-12 school districts. The Energy Commission also provides low interest loans for implementing energy saving strategies through its Energy Efficiency Financing program. Information on these and other programs can be found at http://www.energy.ca.gov/efficiency/financing.html). Projects funded by this program must have a simple payback period of 13 years or less, based on energy savings. This payback should be fairly easy to meet by appropriately selected and installed R-ICLS projects.

ASHRAE standards mandate a maximum lighting power density of 1.4W/ft^2 (ASHRAE 90.1 – 2007) for classrooms when calculated using the space-by-space method. The 2008 and 2013, California Title 24 Building Energy Efficiency Codes require lighting power densities in new classrooms to not exceed 1.2 W/ft^2. The ICLS lighting power density is generally at or below 1.0 W/ft^2.

In some cases, the energy savings and simple payback associated with lowering the LPD may be even better if the pre-existing classrooms have a very high LPD. The pre-existing classroom

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1*California Department of Education Fact Book* 2009.

2 *McGraw-Hill Education Green Building Smartmarket Report* 2007.

3 Ibid 2.

LPD should always be examined to ensure that the R-ICLS installation will in fact reduce energy use.

The R-ICLS system has benefits that go beyond energy savings, which include the ability to tune the light level for a specific task, less visual and computer glare, and easily accessible lighting controls.

CHAPTER 4:
Survey Available Technologies

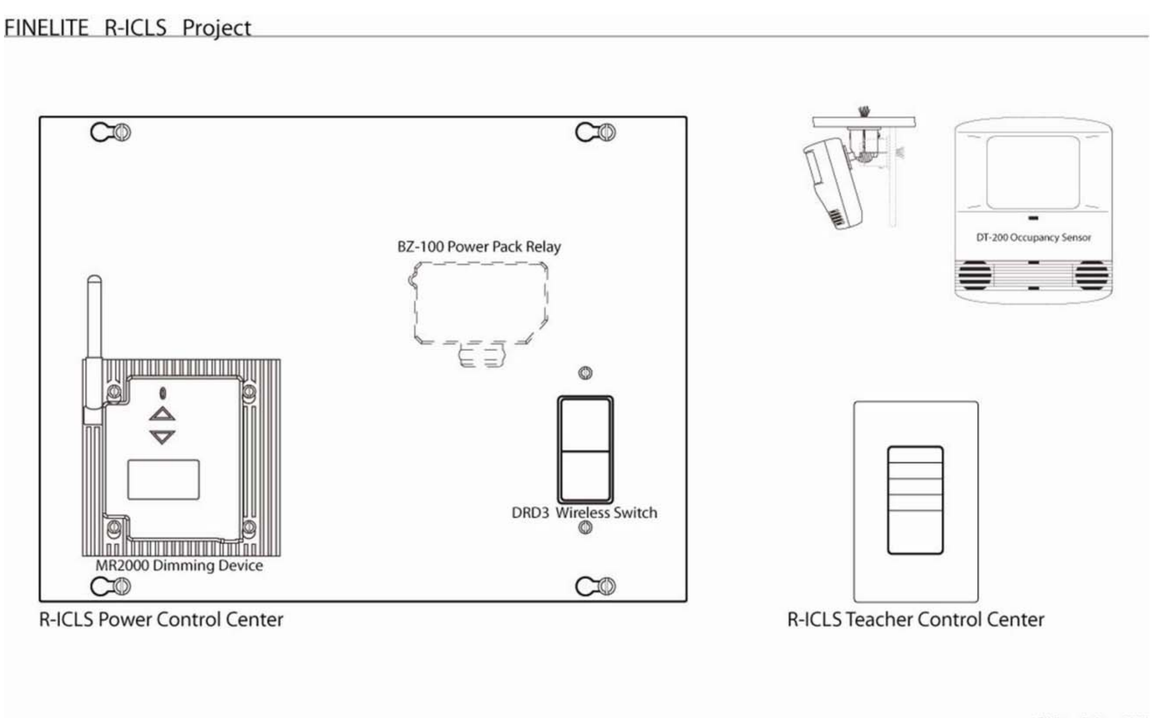
Finelite and the CLTC surveyed the available technologies to achieve luminaire control with the following requirements.

- Eliminate the need to penetrate the ceiling
- Eliminate the need to run excess electrical conduit or low voltage dimming line.
- Controls could not be battery powered or remotes (not physically mounted to the wall)
- The system will achieve an audiovisual mode
- The system must be robust to accommodate the long life of educational facilities
- The system developed must not cause interference between classrooms

Given the requirements, the system that was developed is shown in Figure 3 and uses radio frequency technology that enabled the team to install control devices without the need to run additional wiring. The system can be installed below the ceiling and is configured to be classroom specific, keeping controls from talking to other classrooms.

A list of components was developed and is described in the next section. The common components that are shared by the R-ICLS Good, Better, and Best-Recessed systems are shown first. Any components specific to a particular type of system are listed second in the section.

Figure 3: Diagram of Wireless Control Center Developed by Finelite



4.1. Components Common to “Good, Better, and Best-Recessed” R-ICLS Systems

4.1.1. Wireless Control Center

The Wireless Control Center, shown in Figure 4, used a plenum-rated enclosure to house the control elements of the system, including the WattStopper MR2000 wireless dimming control for controlling the ambient illumination and a simple circuit board to make the installation of the occupancy sensor plug and play. A WattStopper DRD3 wireless switch was included in each box that turns on and off the whiteboard luminaire. The project team did not use the whiteboard control switch in the “Good” classrooms, but included them in all the designs to provide the flexibility that would enable them to be added later should the teachers desire it. A simple terminal block was wired into the box to make installation easier from the contractor’s standpoint. The housing also included the power pack necessary to power the occupancy sensor.

Enclosure: Finelite custom built.

Wireless dimming controller: WattStopper MR2000

Wireless Switch: WattStopper DRD3 v2 (Better and Best-Recessed only)

Power Pack: WattStopper BZ-100E-P

Estimated Price: R-ICLS Good: $433.25, R-ICLS Better & Best: $546.69 [6]

Figure 4: Image of Wireless Control Center Used in R-ICLS Project

6 Pricing represents 5,000 unit volumes.

4.1.2. Ballasts

Existing ballasts were replaced by Osram Sylvania Quicktronic Powersense T8 dimming ballasts. The ballasts provide 100 percent to 5 percent dimming capabilities and featured universal voltage. Dimming leads were capped off as it was not needed when used with the RF controllers. This important fact eliminated the need to run low-voltage line between each luminaire and the control devices, resulting in reduced installation costs.

Osram Sylvania Model #: QTP2x32-T8/Unv Dim

Estimated Price : $60.00[6] per luminaire

4.1.3. Lamps

Existing lamps were replaced with 3100 lumen Super T8 lamps. T8 lamps were used as compared to T5 or T5HO lamps for cost and performance issues. The T5HO lamps generally cost $4 to $5 more than T8 lamps, and Super T8 lamps are more often used in educational facilities, making them more likely to become a school “standard” item. Also, due to the smaller bulb wall, the T5HO lamps exhibit more glare and thus require a lens to prevent excessive glare in the classroom.

The specific brand of T8 lamps was Osram Sylvania. The Super T8 lamps featured a CRI of 85 and carry a rated lamp life of 36,000 hours at 3 hours per start and 42,000 hours at 12 hours per start. 4100k lamps were installed at the request of Davis Unified School District.

Osram Sylvania Model #: F032/841/XPS/ECO

Estimated Price: $6.00

4.1.4. Teacher Control Center

The Teacher Control Center was purchased from WattStopper. The device used was the Miro Decorator House Scene Controller – DRD6 Wall mounted. Labels were printed to capture the specific functions of each button. Note, this manufacturer also offered a hand held device that could be used if running power from above ceiling wasn’t possible. Input from educators was that handheld units were not desirable as they were susceptible to loss.

Figure 5: Image of Teacher Control Center

Referencing Figure 5 from top to bottom, the smaller buttons along the right hand side of the teacher control center performed the following:

- All On – All recessed luminaires in the classroom are turned on
- Blank – To be used for whiteboard control in other ranges
- A/V Mode – Recessed luminaires are dimmed to 50 percent
- Blank - To be used for whiteboard control in other ranges
- All Off – All recessed luminaires in the classrooms are turned off
- The button along the side provided full range dimming

Placement: The Teacher Control Center was placed at the front of the classroom near the whiteboard. The control required line voltage be brought to it and wire mold was used to run the power from above ceiling to its position on the wall.

WattStopper Model #: DRD5-W V2

Estimated Price: $125.25 [7]

4.1.5. Occupancy Sensor

The R-ICLS design used a wall/ceiling mounted occupancy sensor, as seen in Figure 6.. Wall mounting the unit is necessary if access above ceiling is not possible. Also, running the Cat5 cable through wire mold may be necessary.

Figure 6: WattStopper Wall-Mounted Occupancy Sensor

The sensor manufacturer recommended mounting the occupancy sensor 12" from the wireless devices to prevent signal interference. Testing was conducted at the Finelite facility and found a distance of 12-18" was required. However, site conditions make it necessary to have the flexibility to mount the occupancy sensor at different areas in the classroom for optimum coverage. The installations had access above ceiling and the contractor suggested mounting the units to the ceiling to minimize material and labor costs.

Model #: WattStopper DT200

Estimated Price: $193.30 [8]

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7 Pricing represents 5,000 unit volumes.

8 Pricing represents 5,000 unit volumes.

4.1.6. Interconnection Cables

Plenum-rated Cat5 cables were used to make the connection between the Wireless Control Center and the occupancy sensor.

Cat5 cables also were used to connect between data monitoring equipment and the school servers.

Estimated Price: $25.50[8]

4.2. Better Classroom Specific System Components

The "Better" R-ICLS system differed from the "Good" by adding a separate luminaire providing additional light on the whiteboard. This product was placed 30" back from the whiteboard and provided added illumination on the whiteboard. The unit was controlled by the Teacher Control Center, enabling the teacher to turn the luminaire on and off.

4.2.1. Whiteboard Luminaire

Whiteboard luminaires were included in each of the Better classrooms. The units included were the Finelite Series X2O unit (Figure 7) and were specified for the classroom to meet the specific length of the whiteboards on site. The unit used a 3100 Lumen T8 lamp and uses 96 percent reflective white paint to deliver recommended light levels.

Finelite Estimated Material Costs (12' luminaire): $406.50 [9]

Figure 7: Finelite SX2O Whiteboard Luminaire

4.3. Best-Recessed

The "Best-Recessed" classroom solution replaced existing lensed troffers using three T12 lamps with a newly developed High Performance Recessed luminaire by Finelite. The new luminaire used two T5 lamps. These units were provided early in the product development cycle and T8 versions had not yet been developed. These units required different ballasts and lamps as identified below. The "Best-Recessed" classroom solution used all the same components as the "Better" solution including teacher controls, a whiteboard luminaire, wireless control center, and occupancy sensors.

9 District-wide volume pricing.

4.3.1. Ballasts

The high performance luminaires were shipped with Osram Sylvania Powersense T5 dimming ballasts. The ballasts provide 100 percent-5 percent dimming capabilities and featured universal voltage. Dimming leads were capped off as it was not needed when used with the RF controllers.

Osram-Sylvania Model #: QTP2x28T5/UNV Dim TCC

Estimated Price: $60.00 [10] each luminaire

4.3.2. Lamps

As stated above, the luminaires were shipped with T5 lamps due to the product development cycle not aligning with the research project. The research team would have preferred to use T8 for this project. The high performance luminaires were shipped with Osram Sylvania T5 lamps in the 4100k color temperature range to meet district color specification. T5 lamps featured a CRI of 85 and carry a rated lamp life of 20,000 hours at 3 hours per start.

Osram-Sylvania Model #: FP28/841PM/ECO

Estimated Price: $7.25 each

4.3.3. High Performance Recessed Luminaire

The High Performance Recessed luminaire, Figure 8, provided by Finelite used a T5 configuration due to product development timelines. The unit featured a highly reflective matte, white painted upper reflector, and a center white cross blade shielding element that included a lens. The units feature high efficiency and improved visual comfort. As part of the research, this product was commercialized by the manufacturer. The commercialized product is available in multiple cross-sections including one, two, and three T8, T5, or T5HO lamps. The unit delivers up to 87 percent efficiency with T8 lamps and 97 percent efficiency with T5 lamps.

Finelite Estimated Material Costs (two-T8 2x4): $161.00 [11]

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10 Pricing represents 5,000 unit volumes.

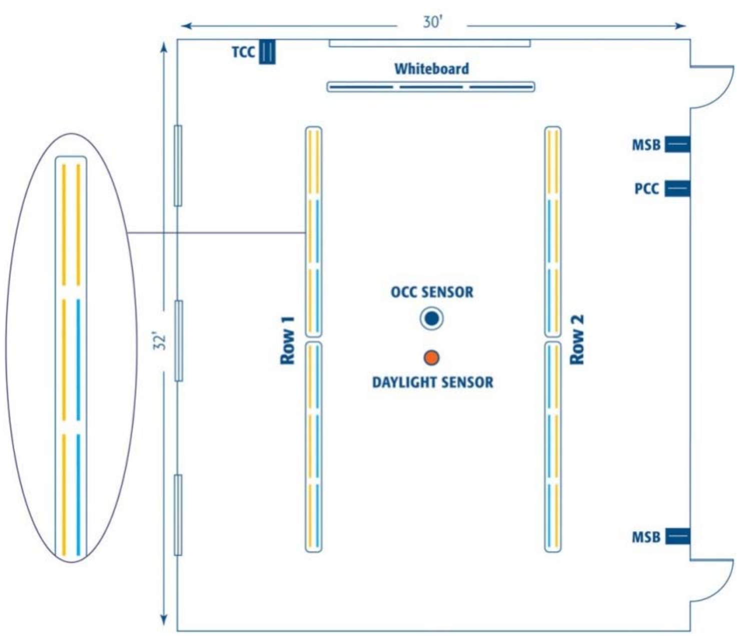
11 District-wide volume pricing.

Figure 8: Finelite High Performance Recessed Luminaire

4.4. Best-Pendant

“Best-Pendant” used the latest version of ICLS that includes two rows of suspended indirect/direct luminaires, a whiteboard luminaire, a Teacher Control Center at the front of the classroom, a power control center, an occupancy sensor, and master on/off controls at each entrance. This system was developed during PIER LRP Project 4.5 research and was changed to use a two T8 switching methodology to be as cost effective as possible. The switching methodology is pictured in Figure 9.

Figure 9: Template Showing R-ICLS Best-Pendant Switching Convention



Best-Pendant featured 2 T8 lamps in a cross section suspended indirect/direct luminaire. During General Mode, all lamps are turned on. During A/V Mode, the first 4’ of luminaire near the A/V screen is turned off as well as a row of lamps in each luminaire row.

4.4.1. Ballasts

Standard instant start non-dimming ballasts were used in the pendant luminaires. Ballasts used for the research project were made by Osram Sylvania.

4.4.2. Lamps

Luminaires were shipped with 3100 lumen “Super T8” lamps. The specific brand of lamps was Osram Sylvania. The lamps provided were 4100k to meet district lamp color standards. The Super T8 lamps featured a CRI of 85 and carry a rated lamp life of 36,000 hours at 3 hours per start and 42000 hours at 12 hours per start.

Osram-Sylvania Model #: F032/841/XPS/ECO

4.4.3. Teacher Control Center

The Teacher Control Center (TCC), shown in Figure 10, places simple effective control at the front of the classroom. The TCC provided the ability to switch between General and A/V Mode, the ability to turn on the whiteboard luminaire, and have control to override the occupancy sensor for 1 hour through the use of a “Quiet Time” switch.

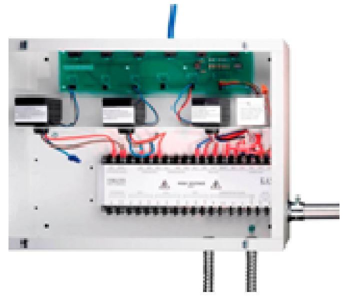
The TCC was connected to the system through the use of Cat5 cables that reduce the need for contractor-supplied materials, labor, and reduced the potential for wiring errors. The TCC was placed at the front of the classroom near the whiteboard. Wiremold was used to run the Cat5 cable to a surface mounted junction box that housed the TCC.

Figure 10: Teacher Control Center Used for Best-Pendant

4.4.4. Power Control Center

The Power Control Center (PCC) is pre-wired at the factory and reduces labor and material requirements for contractors. The PCC takes line voltage in from building power and then carries power to and communicates with ICLS components. The unit can be installed below ceiling and wiring is run along the wall or ceiling using wiremold type products.

Figure 11: Power Control Center



4.4.5. Occupancy Sensor

The system used a ceiling-mounted dual- technology occupancy sensor with Quiet Time override control. The sensor was mounted between the two rows in the center of the classroom. It was connected to the PCC via low voltage plug and play wiring. The Quiet Time override on the Teacher Control Center provides 60 minute occupancy sensor override for use in periods of limited movement. This ensures the lights will not turn off unexpectedly and thus cause disruption. If access above ceiling is restricted, a suitable wall-mounted unit may be used.

Figure 12: WattStopper Dual-Technology Occupancy Sensor

4.4.6. Interconnection Cables

Plenum-rated plug-and-play Cat5 cables were supplied by Finelite in the lengths necessary for installation. The interconnection cables connected the TCC and occupancy sensor to the PCC minimizing labor and materials.

4.4.7. Whiteboard Luminaire

Whiteboard luminaires, as shown in Figure 7, were included in each of the Better classrooms. The units included were the Finelite Series X20 unit and were specified by classroom to meet the specific length of the whiteboards on site. The unit uses a 3100 Lumen T8 lamp.

4.4.8. Pendant Luminaires

The ambient luminaires used in this installation were Series X1O by Finelite. These Indirect/Direct luminaires provide the appropriate balance of uplight and downlight with excellent glare control.

The unique feature required for the retrofit installation is the ability to have adjustable mounting points. This unit (shown below) has an optional adjustable bracket to accommodate existing mounting points. The design team specified this option to accommodate installations where above ceiling access was not feasible. However, even with above ceiling access, the

Franklin Elementary School site required the use of adjustable mounting points. Duct work above ceiling and other obstructions made this feature important.

Figure 13: Adjustable Mounting Bracket for Pendant Luminaires

4.4.9. Master On/Off Controls

Existing master on/off controls were used to provide control over individual luminaire rows.

4.4.10 Switching Convention to Achieve A/V

The original PIER LRP Project 4.5 research that established this type of classroom lighting used a 2-T8/1-T8 cross section. The center lamp was isolated using a highly reflective optical element to achieve the A/V Mode. For the R-ICLS project, the project team focused on a 2-T8 cross-section luminaire and a different switching strategy. This luminaire strategy minimized the number of lamps and ballasts, making it more economical. A/V Mode is achieved by switching the first four feet of luminaire off (near the A/V Screen) as well as one entire row of lamps in each luminaire row.

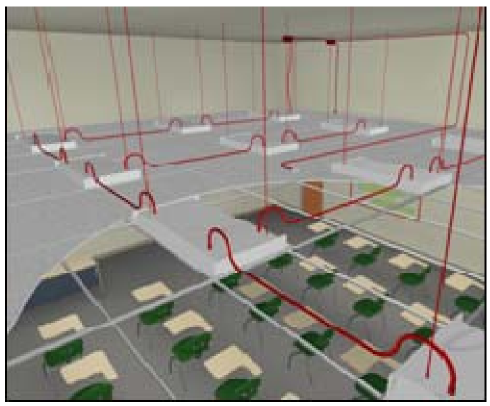
Total estimated ICLS System Cost for the "Best-Pendant" system is $3,916 [12].

12 Pricing represents district-wide volumes. Includes luminaires, ballasts, sensors, controls, and plug and play wiring.

CHAPTER 5:
Develop Three Levels of R-ICLS

Retrofit projects minimize costs by reducing construction labor and materials. The budget does not accommodate rebuilding space, rewiring, or adding additional ceiling supports. Retrofitting existing luminaires or replacing them with those of similar form factor ensures the existing supports and electrical feeds can be used, drastically reducing installation costs. The R-ICLS templates developed during this project address the two most common fixture types used in classrooms: recessed 2x4 and suspended linear fluorescent luminaires.

Figure 14: Above-Ceiling Rendering Showing Ceiling Supports, Flex Conduit



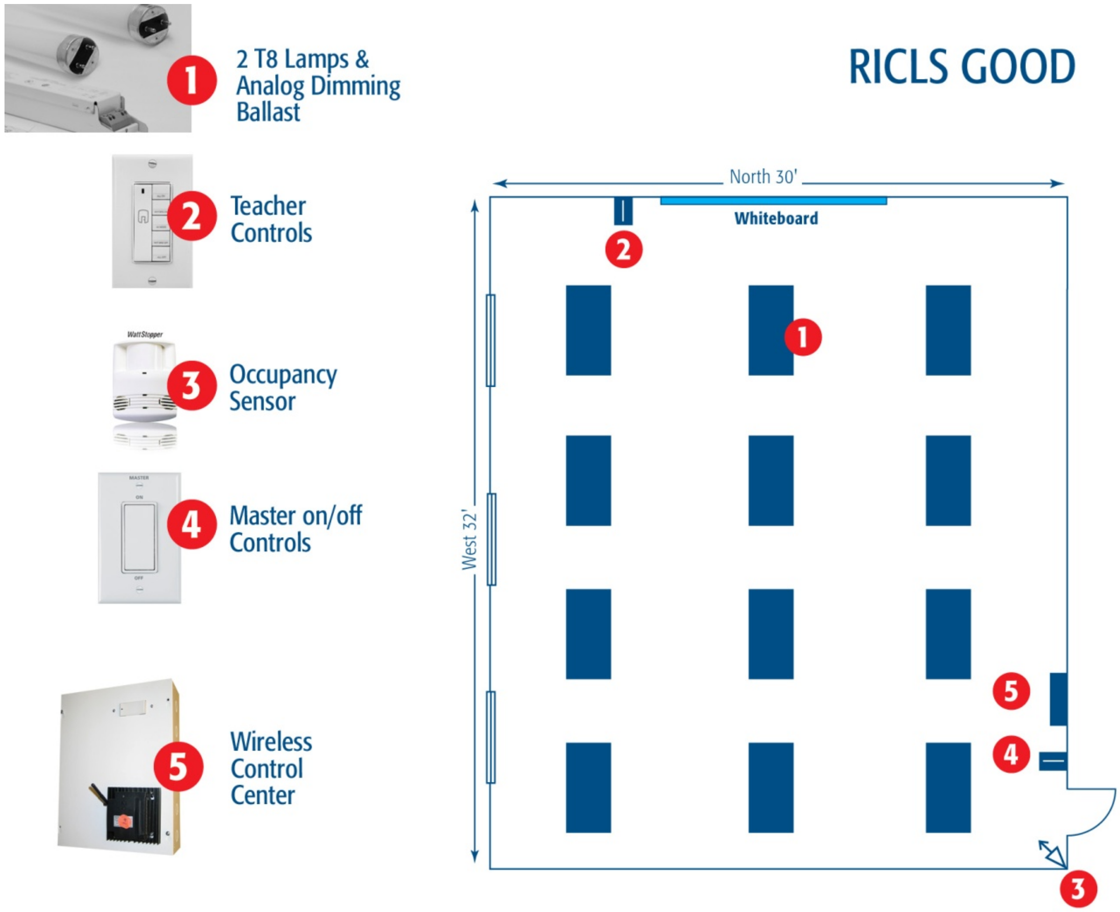
Existing recessed luminaire layouts have existing ceiling supports and electrical conduit in place. Changing the layout of the luminaires would require installation of additional ceiling supports and running new electrical conduit, as shown in Figure 14. This requires additional labor and material costs, which adds to the payback timeline.

After reviewing the available technology and budgetary requirements, Finelite and the CLTC developed distinct solutions for recessed and pendant product applications. Classrooms with existing recessed products were to be retrofitted using the same products to reduce installation costs by using existing ceiling supports and electrical feeds.

5.1. Good

The "Good" product level delivers improved lighting quality by improving lamp color and illumination levels more in line with best practices, energy savings, and improved teacher control. Figure 15 details the components necessary for the "good" retrofit classroom. Luminaire layouts are not changed in the retrofit application due to cost considerations. Descriptions of the components were provided in Chapter 4.

Figure 15: R-ICLS Good Template



5.1.1. Template Components

The following details the typical installation considerations:

- Replace lamps and ballasts: old technology lamps and ballasts are replaced. Luminaires may be changed to two-T8 cross-section. Use high lumen "super T8" lamps. Replace sockets as necessary. Inefficient ballasts are replaced with analog 0-10v dimming ballasts. The low voltage dimming leads from the ballast are capped off. There is no need to run low voltage wiring from ballasts to the controls, which is important for situations where above ceiling access is not feasible.
- Install Teacher Control Center at the front of the classroom: wireless controls are installed at the front of the classroom. In general, the best placement is close to the whiteboard. As the retrofit classroom often has a defined occupant and layout, input from the user can be obtained for maximum occupant satisfaction. In the absence of this input, placement on the front teaching wall nearest the teacher desk is optimal. The wireless control used requires 120v power and may be easily run to the control using wiremold products. No batteries are required for this control. The Teacher Control

Center allowed the teacher to switch between a General and A/V Mode, turn the luminaires all off, and dim the luminaires manually from full output down to 5 percent.

- Install dual technology occupancy sensors: install wall-mounted occupancy sensors in classrooms that do not currently have them installed. Classrooms with existing sensors should be updated to the new technology occupancy sensors to ensure minimal disruption in the classroom. The R-ICLS sensor received power and control via cat5 cable from the Wireless Control Center. This low voltage line can be run along the ceiling line or encased in a wiremold product.
- Use existing Master On/Off controls – In general, existing on/off controls located by the doors can be reused.
- Wireless Control Center – The Wireless Control Center contains all wireless elements used to control the luminaires. This unit is installed either above ceiling (if feasible) or on a classroom wall. It requires 120v to power the individual units. The units should be set up by the manufacturer to reduce on-site labor.

5.1.2. System Benefits

The system improves the lighting quality in the classroom through the use of high quality lamps and ballasts. Light levels are reduced to levels recommended by best practices, thus reducing the potential for glare. The teacher controls improve user satisfaction enabling them to control their environment. The A/V Mode dramatically improves the ability to have the appropriate light level for audiovisual presentations. The improved occupancy sensors should reduce the potential for false offs.

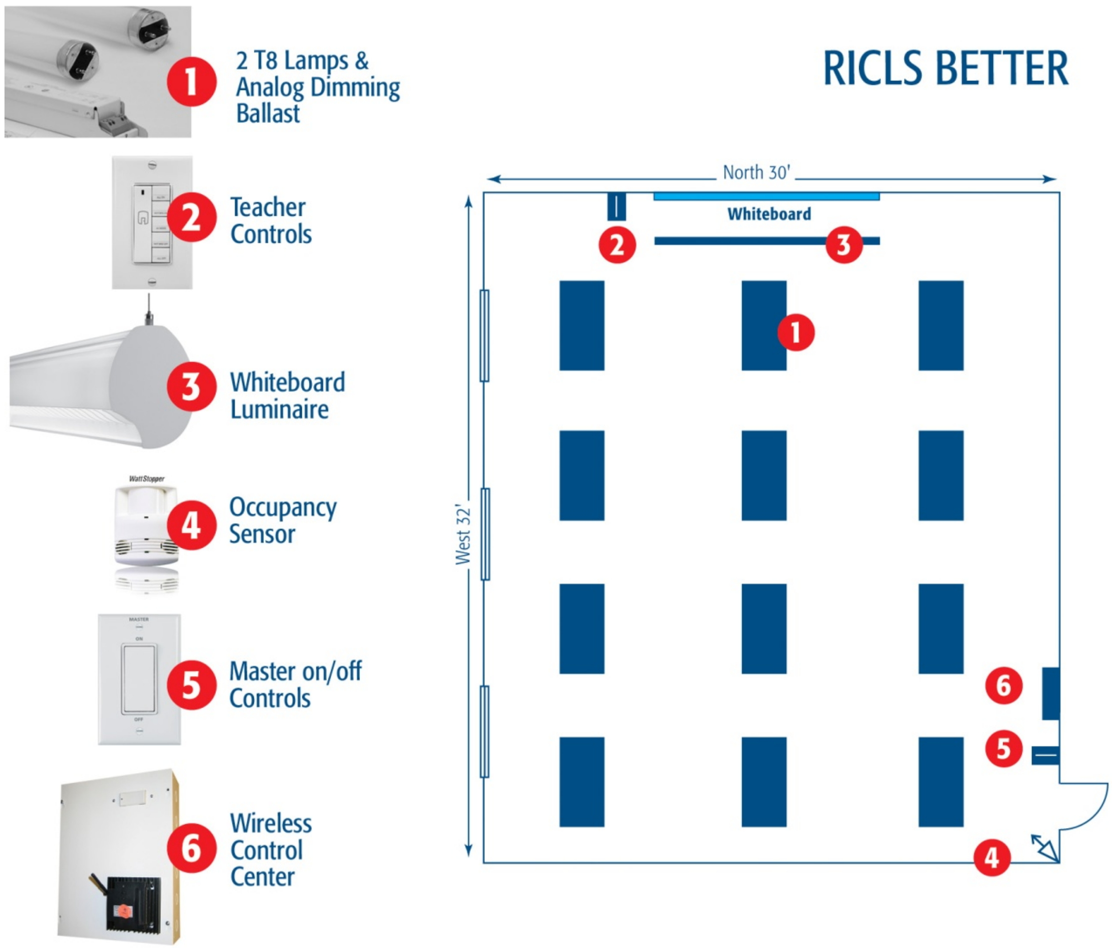
Energy savings are achieved through reducing the number of lamps in the luminaire and updating the lamp and ballast technology. Additional savings are achieved through the A/V Mode which dims the lamps to 50 percent of light output. The improved occupancy sensor technology also improves the effectiveness of the system ensuring the lights are turned off when the room is not in use.

The R-ICLS “Good” system uses the existing electrical and luminaire supports, thus minimizing contractor labor and materials. The use of the wireless controls eliminates the need to run control wires from each luminaire to the teacher controls.

5.2. Better

The “Better” product level included all the elements of the “Good” system and improves lighting quality by adding a whiteboard luminaire. The whiteboard is a vital communication element in the classroom and a task-specific luminaire is used to increase the illuminance levels, which improves the ability for students to read material written on the board. The whiteboard luminaire is placed near the whiteboard and setback approximately 24-30” from the whiteboard. An additional button is included on the Teacher Control Center, providing on/off control of the luminaire. A template of this option is shown in Figure 16.

Figure 16: R-ICLS Better Template



5.2.1. Template Components

The typical installation considerations are the same as those listed for the "Good" product level with the addition of the whiteboard luminaire and control:

- Install a Whiteboard Luminaire – A task-specific luminaire is installed to increase the illuminance levels, which improves the ability for students to read material written on the board. The whiteboard luminaire is placed and setback approximately 24-30" from the whiteboard. An additional button is included on the Teacher Control Center providing on/off control over the luminaire.

5.2.2. System Benefits

Benefits are the same as the "Good" product level with improved light levels within the classroom, energy savings, and reduced labor costs. The addition of the whiteboard luminaire places recommended light levels on the whiteboard improving the students' ability to read written text. The added control for the whiteboard luminaire to the Teacher Control Center improves user satisfaction enabling them to further control their environment.

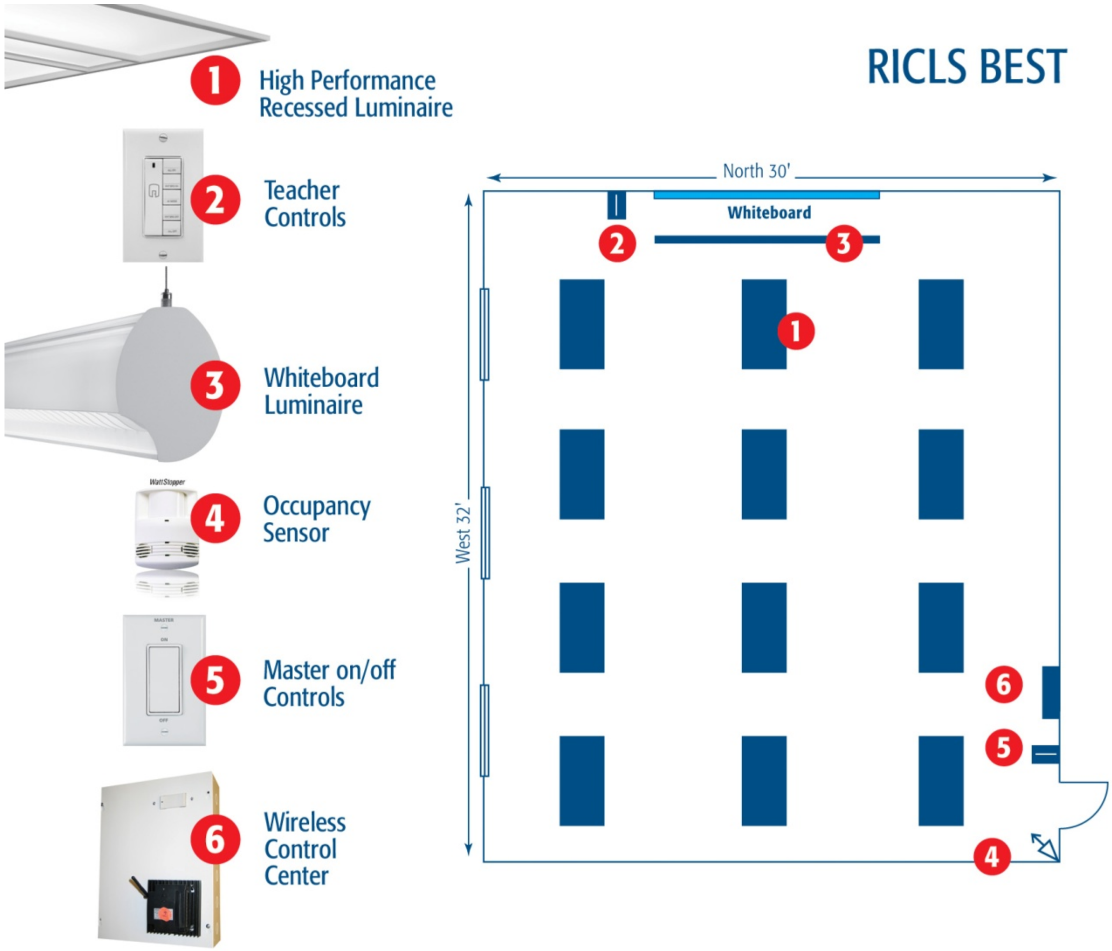
5.3. Best-Recessed

R-ICLS "Best-Recessed" is similar to R-ICLS "Better" with one exception: new high quality luminaires replace existing luminaires. The luminaires were changed with luminaires of the same form factor (2x4) to eliminate the need to change ceiling tiles or run additional electrical conduit.

R-ICLS Best-Recessed replaces existing recessed luminaires with higher performance recessed products. It is important to change recessed luminaires with recessed luminaires of similar shape to use the same supports and electrical connections, thus reducing installation costs. The new luminaire developed by Finelite reduces glare in the classroom and enables the use of fewer lamps or luminaires to produce the same amount of light as traditional recessed products.

Similar luminaires are now available from a variety major lighting manufacturers. Lighting quality is further enhanced through the addition of a whiteboard luminaire. A template of this option is shown in Figure 17.

Figure 17: R-ICLS Best-Recessed Template



5.3.1. Template Components

The typical installation considerations are the same as those listed for the "Good" and "Better" product levels with the addition of replacing the recessed luminaires.

- Replace luminaires with high performance recessed luminaires: Typically recessed luminaires to be retrofitted are either parabolic or lensed units and 2x4 in shape. A new product class is available and called high performance recessed luminaire. These luminaires are more efficient and effective at delivering light higher on the wall while reducing overall glare in the space. Luminaires can be changed to 2-T8 cross-section, using high lumen "super T8" lamps. Luminaires are received from the manufacturer pre-wired with dimming ballasts. Contractors need to remove the existing luminaire, install the new luminaire, use existing ceiling supports, and make electrical connections using existing electrical connections. The luminaire used for the project was developed by Finelite. The unit features high reflectance white paint and optical systems that minimize glare while distributing light higher on the walls. The luminaire is detailed further in the Project Outcomes section of this report, Section ______.

5.3.2. System Benefits

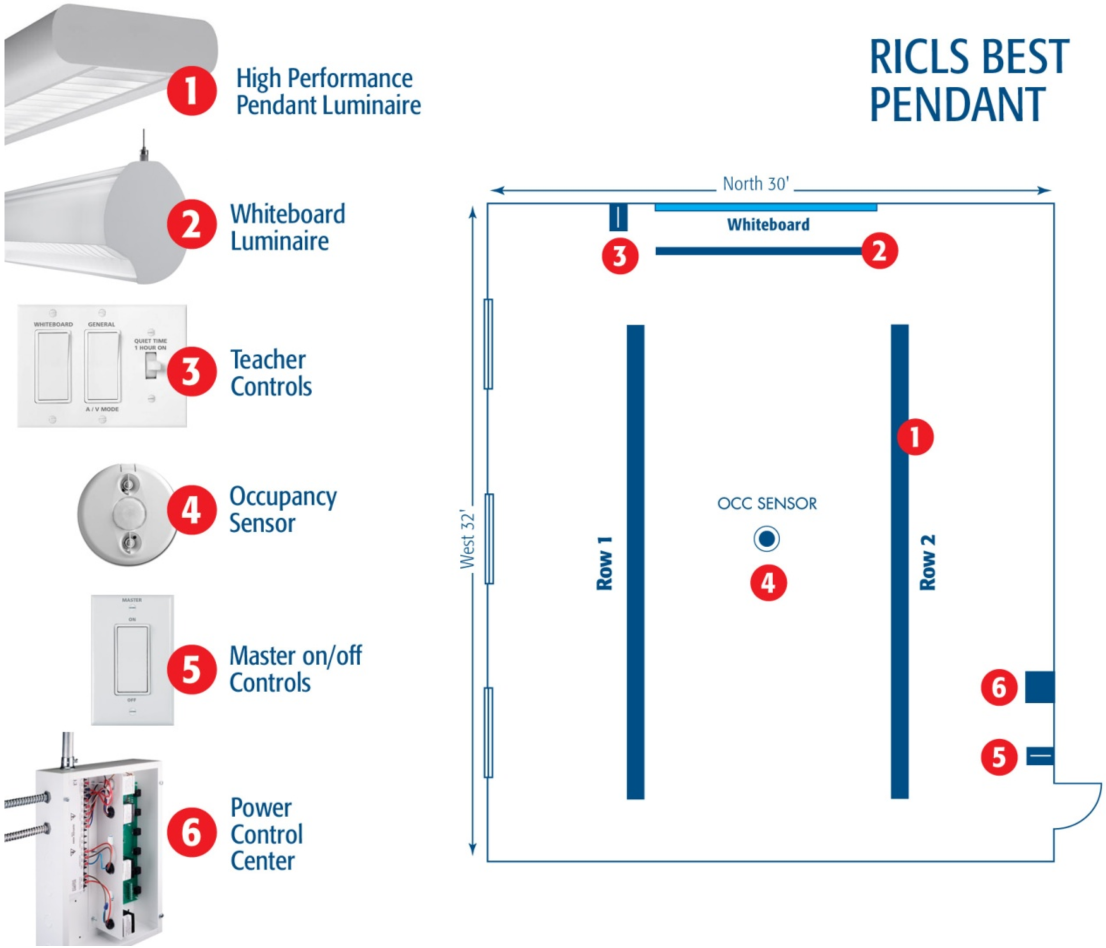
Benefits are the same as the "Good" and "Better" product levels with improved light levels within the classroom, energy savings, and reduced labor costs. Additionally, the system dramatically improves the lighting quality through the use of a high performing recessed luminaire that reduces glare in the classroom while improving the light distribution. Light levels are reduced to levels recommended by best practices, thus reducing the potential for glare.

The R-ICLS "Best-Recessed" option uses the existing electrical and luminaire supports thus minimizing contractor labor and materials. The use of the wireless controls eliminates the need to run control wires from each luminaire to the teacher controls.

5.4. Best-Pendant

The "Best-Pendant" solution was added to the research to accommodate the classrooms in California that have pre-existing pendant luminaires. These older pendant luminaires generally feature outdated optical performance and often use old T12 lamp technology. Similar to "Best-Recessed", the design focused on changing pendant luminaires with high performing pendant luminaires as opposed to changing to other products such as recessed. The benefit is the same mounting points and feed locations can be used with no need to run additional ceiling supports or additional wiring in the ceiling. A template of this option is shown in Figure 18.

Figure 18: R-ICLS Best Pendant Template



5.4.1. Template Components

The typical installation considerations are the same as those listed for the "Good", "Better", and "Best-Recessed" product levels with the addition of replacing the pendant luminaires, enhanced teacher controls, and a power control center.

- Replace existing luminaires with new high performance pendant luminaires - The "Best-Pendant" solution offered is a style of Integrated Classroom Lighting System developed through PIER LRP Project 4.5 research. This new system features a 2-lamp cross-section luminaire instead of the 2-T8/1-T8 system developed for PIER LRP Project 4.5. The A/V mode in this system is achieved by switching off the first four feet of each luminaire row in addition to one row of lamps along the entire row. When switched to A/V Mode, the amount of light is reduced on the projection screen or interactive whiteboard and light levels in the room are reduced while still providing enough illumination in the classroom for note-taking and maintaining eye contact. This particular luminaire set up was included in R-ICLS as it requires fewer lamps and ballasts, making it more suitable for retrofit situations by reducing system costs.

- Luminaires must include an adjustable mounting system to facilitate easier installation and reduction in materials. The adjustable mounting enables the contractor to use existing ceiling supports.
- Install an enhanced Teacher Control Center at the front of the classroom – Teacher controls are located at the front of the classroom. The teacher can control the lighting and change between General and A/V mode, turn on and off the whiteboard luminaire, and control the occupancy sensor with a simple bypass that gives the teacher control over the occupancy sensor for 60 minutes. During that time the occupancy sensor will not turn off the lights. This "Quiet Time" switch is used during testing or other periods where movement is going to be limited to a degree that might result in the sensor turning off the lights unexpectedly.
- Power Control Center – Finelite, the manufacturer who supplied the ICLS system, places all the relays and electrical connections into a plenum rated box, which reduces installation time and materials.

5.4.2. System Benefits

Benefits are the same as the "Good", "Better", and "Best-Recessed" product levels with improved light levels within the classroom, energy savings, and reduced labor costs. The high performance pendant system dramatically improves the lighting quality by updating the lamp and ballast quality. New luminaire design delivers better light distribution making it possible to reduce luminaire counts. The system gives the teacher an A/V Mode that yields improves contrast on the projection screen while having enough light in the classroom to keep students alert, and for note taking.

Energy savings is achieved through reducing the number of luminaires and lamps, as well as updating to more energy-efficient ballasts. Additional savings is achieved through the A/V Mode. The energy consumption in General Mode is approximately 0.9 Watts/ ft^2. The energy consumption in A/V Mode is less than 0.5 Watts/ ft^2 and can typically be designed to consume just 0.35 Watts/ ft^2.

CHAPTER 6:
Deploy and Monitor R-ICLS Systems in Classrooms

Three school sites were selected to install the R-ICLS test classrooms: two schools from Davis Unified School District and one school from Loomis Unified School District.

6.1. Site Locations

Davis Joint Unified School District supported the research by offering two school locations where the Good, Better, and Best-Recessed products could be installed and monitored. Three test classrooms were installed in North Davis Elementary School. Six test classrooms were installed in Davis High School. Loomis Unified School District provided four classrooms at Franklin Elementary School to test the Best-Pendant solution.

6.1.1. R-ICLS "Good" Classroom

At Davis High School, the R-ICLS Good installations were in Rooms O4, O5, and O6. Figure 19 shows one of the post-retrofit classrooms. Luminaires in two of the rooms used 4-T8 lamps. The third room had not been retrofitted previously and still had 4-T12 lamps. Each room had 12 2x4 luminaires.

Figure 19: Post-Retrofit, Davis High School – Davis, CA

Table 3 shows the change in illumination levels as well as the change in energy levels pre- and post-retrofit. It is important to note that the LPD in A/V Mode is not presented here due to lack of linearity between light output and energy consumption. Fifty-three percent power savings is achieved between the post retrofit in the general mode versus the pre-retrofit situation.

Table 3: Davis High School R-ICLS Good Energy and Footcandle (fc) Levels

	Pre-Retrofit	Post Retrofit General Mode	Post Retrofit A/V Mode
Illumination Levels (fc)	105	60	25
Energy Level (LPD)	1.55 W/ft^2	0.73 W/ft^2	

R-ICLS "Good" improves the lighting quality, reduces energy consumption, and enhances teacher control for classrooms with recessed luminaires. Teacher controls are placed at the front of the classroom, giving teachers the ability to change the lighting to a level that improves the contrast of audiovisual presentations while having enough light to keep students awake, allow teachers to see student faces, and for note taking. Luminaires were changed to 2-T8lamps. In general, light levels were maintained or decreased slightly, and energy levels were reduced. High color rendering T8 lamps were used, which improved the color and feel of the classroom. Ballasts were changed to analog dimming ballasts giving teachers the ability to dim lamps. A dual technology wall-mounted occupancy was installed to yield additional energy savings.

R-ICLS is an excellent solution for most school districts who want to retrofit classrooms while improving the learning environment. R-ICLS "Good" costs more to install than a standard lamp/ballast retrofit. However, the system yields dramatic improvements to the learning environment with the addition of an A/V mode and teacher controls.

The system cost and associated energy savings provides acceptable payback timelines. Also, the energy savings that result from the additional lighting control will deliver more operating savings than a standard lamp/ballast retrofit. As teachers use more A/V presentations, energy savings increase. R-ICLS "Good" is not a viable option for classrooms with pendant luminaires. As mentioned, the unique product design and luminaire layouts make it too costly to rewire to achieve similar results as found in recessed luminaires.

R-ICLS "Good" took a minimum of contractor supplied parts. Payback timelines may range from 1.8 to 6 years depending on existing site conditions.

6.1.2. R-ICLS "Better" Classroom

At Davis High School, the R-ICLS Better installations were in Rooms N10, N11, and N12. Rooms N10 and N11 were monitored using data loggers. Figure 20 shows one of the post-retrofit classrooms.

Luminaires in these rooms had previously been retrofitted to 2-T8 lamps (25w). Each room had 18 2x4 luminaires. A slightly higher LPD was measured in the post retrofit application due to the use of dimming ballasts, 32w lamps, and the addition of the whiteboard. The research team selected this site to get the data on a room with a larger number of luminaires. The collected data would be used to develop different scenarios (for example, if the room had been laid out with T12 lamps).

Figure 20: Post-Retrofit, Davis High School – Davis CA

Table 4 shows the change in illumination levels as well as the change in energy levels pre- and post-retrofit. It is important to note that the LPD in A/V Mode is not presented here due to lack of linearity between light output and energy consumption. Negative power savings is seen due to existing luminaire layout.

Table 4: Davis High School R-ICLS Better Energy and FC Levels

	Pre-Retrofit	Post Retrofit General Mode	Post Retrofit A/V Mode
Illumination Levels (fc)	59	60	26
Energy Level (LPD)	1.18 W/ft^2	1.35 W/ft^2	

R-ICLS “Better” improves the lighting quality, reduces energy consumption, and enhances teacher control by changing existing classroom lighting system in the same manner as R-ICLS “Good”. It improves upon the “Good” system category with the addition of a dedicated whiteboard luminaire. The luminaire adds additional illumination on the teaching wall.

R-ICLS “Better” was not found to be a viable solution for classrooms with either recessed or pendant luminaires. Unlike new construction projects, classroom retrofits with recessed luminaires do not allow for layout changes, which results in higher than needed illumination levels. The value of the task-specific whiteboard luminaire is not realized in this situation. As the value to the learning environment is not enhanced, the added cost makes the payback timelines longer than acceptable.

Similar to R-ICLS "Good", the "Better" system configuration took a minimum of contractor supplied parts.

6.1.3. R-ICLS "Best-Recessed" Classroom

The R-ICLS Best-Recessed installations at Davis North Elementary occurred in Rooms E31, E32, and E33. E31 and E32 were monitored using data loggers. Luminaires used in R-ICLS "Best-Recessed" were developed by Finelite and are commercially available.

Figure 21 and Figure 22 show examples of post-retrofit classrooms.

Figure 21: Post-Retrofit – General Mode, North Elementary School– Davis, CA

Figure 22: Post-Retrofit – A/V Mode, Davis North Elementary – Davis, CA

Luminaires in these rooms had 4-T12 lamps in cross-section. Each room was retrofitted with 12 2x4 luminaires of the type shown in Figure 23.

Figure 23: Rendering of Finelite High Performance Recessed Luminaire

Table 5 shows the change in illumination levels as well as the change in energy levels pre- and post-retrofit. It is important to note that the LPD in A/V Mode is not presented here due to lack of linearity between light output and energy consumption. 54 percent power savings is achieved between the post retrofit in the general mode versus the pre-retrofit situation.

Table 5: Davis North Elementary – Energy and FC Levels

	Pre-Retrofit	Post Retrofit General Mode	Post Retrofit A/V Mode
Illumination Levels (fc)	90	65	28
Energy Level (LPD)	1.92 W/ft^2	0.89 W/ft^2	

R-ICLS "Best-Recessed" improves the lighting quality, reduces energy consumption, and enhances teacher control by replacing one for one existing luminaire with new high performance recessed luminaires. New luminaires were developed for the R-ICLS project that yield increased luminaire efficiency with better visual comfort. The same controls and audiovisual functionality as used in R-ICLS "Good" and "Better" are used in the "Best-Recessed" system category. A supplemental whiteboard luminaire is added to R-ICLS "Best-Recessed" to add vertical illumination on the whiteboard.

R-ICLS "Best-Recessed" is viable for school districts. The lighting quality is improved by replacing the luminaires one-for-one with high-performance recessed luminaires. This is a great solution for schools that want to improve the lighting quality and energy efficiency at costs significantly below major remodels.

The R-ICLS "Best" system configuration took a minimum of contractor supplied. R-ICLS "Best" added high performance recessed luminaires that dramatically improved lighting quality, which represents around 50 percent of the installed costs. Payback timelines may range from 12 years to under 4 years depending on existing site conditions.

6.1.4. R-ICLS "Best-Pendant" Test Classrooms

Franklin Elementary School demonstrated the R-ICLS Best-Pendant retrofit in Rooms 19, 21, 22, and 23. Rooms 19 and 23 were monitored using data loggers. An example of pre- and post-retrofit illumination is shown in **Error! Reference source not found.**.

Figure 24: Pre-Retrofit Pendant Classroom, Franklin Elementary – Loomis, CA

Figure 25: Post-Retrofit Pendant Classroom, Franklin Elementary – Loomis, CA

The pre-retrofit classrooms had three rows of T12 pendant luminaires. Table 6 shows the change in illumination levels as well as the change in energy levels pre- and post-retrofit. 79 percent power savings is achieved between the post retrofit in the general mode versus the pre-retrofit situation.

Table 6: Franklin Elementary – Energy and FC Levels

	Pre-Retrofit	Post Retrofit General Mode	Post Retrofit A/V Mode
Illumination Levels	67fc	53fc	21fc
Energy Level (LPD)	4.26 W/ft^2	0.88 W/ft^2	0.35 W/ft^2

R-ICLS "Best-Pendant" improves the lighting quality, reduces energy consumption, and enhances teacher control by replacing old pendant luminaires with new high performance luminaires. The luminaire layout was changed which dramatically improved the energy savings potential. A whiteboard luminaire was added to increase the vertical illumination on the whiteboard. Teacher controls were placed at the front of the classroom enabling teachers to change between a General Mode and A/V Mode. A dual technology occupancy sensor is included. Master controls at the door provide on/off lighting control.

R-ICLS "Best-Pendant" is a great solution for schools with existing pendant luminaires. Many of these layouts use old lamp technology and the best opportunity for savings and improving the learning environment is to update the classroom with new high performance luminaires that deliver better quality, lighting modes that improve the contrast of A/V presentations, and easily accessible teacher controls. It is important to select a luminaire that uses the adjustable suspension brackets, which enable contractors to use existing ceiling supports and electrical connections.

The Franklin Elementary site had 3 rows of 2-lamp pendant luminaires with VHO T12 lamps and magnetic ballasts. Payback timelines run from more than 12 years to less than 4 years depending on existing site conditions.

The unique construction and layout of pendant luminaire systems requires a different approach from recessed luminaires retrofit scenarios. Older design philosophy and luminaire efficiency led to using more luminaires than necessary. Today's luminaires are much more efficient and two rows of luminaires can now do what previously took three rows. The wiring of pendant luminaires changes by configuration and luminaire design making "Good" and "Better" options not viable. The pendant retrofit decision is therefore to either simply replace the lamps with lower wattage T8 lamps or change out the luminaires. Changing luminaire layouts dramatically improves the lighting quality and yields the greatest energy savings.

6.1.5. Data Monitoring

A detailed report on the data collection methodology is available is in Appendix D. In general, two classrooms at each R-ICLS site were connected to data monitoring equipment that tracked system usage for an entire school year. The information from the data loggers was collected and transmitted via local school network systems to a database located on Finelite's server. Custom software was developed to organize the data.

The data collection started in August and September of 2008 and continued until May or June (dependent on school district year end) of 2009.

6.1.6. Data Collection Hardware

The data collection hardware, as seen in Figure 26**Error! Reference source not found.**, was made into an assembly comprised of the data logger, current sensors, temperature sensors, and a networking device for data transmission. This unit was installed by the contractor while Finelite coordinated with the district information technology (IT) personnel to establish data transmission connection.

Figure 26: Monitoring Equipment Housing

6.1.7. Data Collected

Data collected on sites with data loggers included the following:

- A/V Gen Switches: The count of the number of times the teacher switched between General and A/V Mode.
- A/V Use (#/Day): The count of the number of times the teacher used the A/V Mode. As dimming was used to achieve A/V Mode, a threshold of 90 percent was established. This means anytime the teacher dimmed the luminaires below 90 percent output, it was considered the A/V Mode.
- WB Use (#/Day): The count of the number of times the teacher turned on the whiteboard.
- General Total Min: The total minutes spent using the General Mode.
- Whiteboard Total Min: The total minutes spent using the whiteboard luminaire.
- A/V Total Min: The total minutes spent using the A/V Mode.
- Settle Time: The total minutes spent in the Settle Mode (A/V Mode with the Whiteboard luminaire on). Settle Time is only counted in R-ICLS “Better” and “Best” classrooms.

- Settle Count: The number of times the Settle Mode was used.
- Quiet Count: The number of times the Quiet Time switch was used. The Quiet Time switch bypasses the occupancy sensor for 60 minutes. This was only used in the "Best-Pendant" test classrooms at Franklin for R-ICLS.
- Occ Sensor Shut Off: The number of times the occupancy sensor shut off the lights.
- Manual Shut Off: The number of times the teacher used the Main Switch Bank to turn off the lights.
- Lights On Total: The total amount of time the lights were on during the day.
- Watts/ ft^2: This is a calculated result showing the Watts/ ft^2 consumed.
- kWh: This is a calculated result showing the energy consumed in kWh.

6.1.8. Data Collection Reports

Distinct report outputs were generated using custom software developed by Finelite. These reports track daily usage in a tabular format, present a visual representation of usage throughout the day, and produce a summary of usage over a set period of time. Figure 28: Visual Representation of System Usage for R-ICLS "Best-Recessed" for Same Classroom on May 28, 2009 and Figure 29: Visual Representation of System Usage in R-ICLS "Best-Pendant"

show all activity throughout two particular days in a North Elementary classroom. The chart shows exactly when the teacher changes from General to A/V Mode, when the whiteboard luminaire is turned on, when the luminaires are turned off either manually or by the sensor, and the time period of each particular mode. The data in the chart shows how the teacher uses the lighting throughout the day to meet the changing needs of the curriculum. It also demonstrates the importance of controls at the front of the classroom, as previous studies found controls at the back of the classroom would not be used to change modes to this extent.

Figure 27 shows another example of how one teacher at Franklin Elementary used the controls to change between General and A/V Mode, and used the whiteboard luminaire in conjunction with General Mode for the latter part of the day.

Figure 27: Visual Representation of System Usage in R-ICLS "Best-Recessed" on May 12, 2009

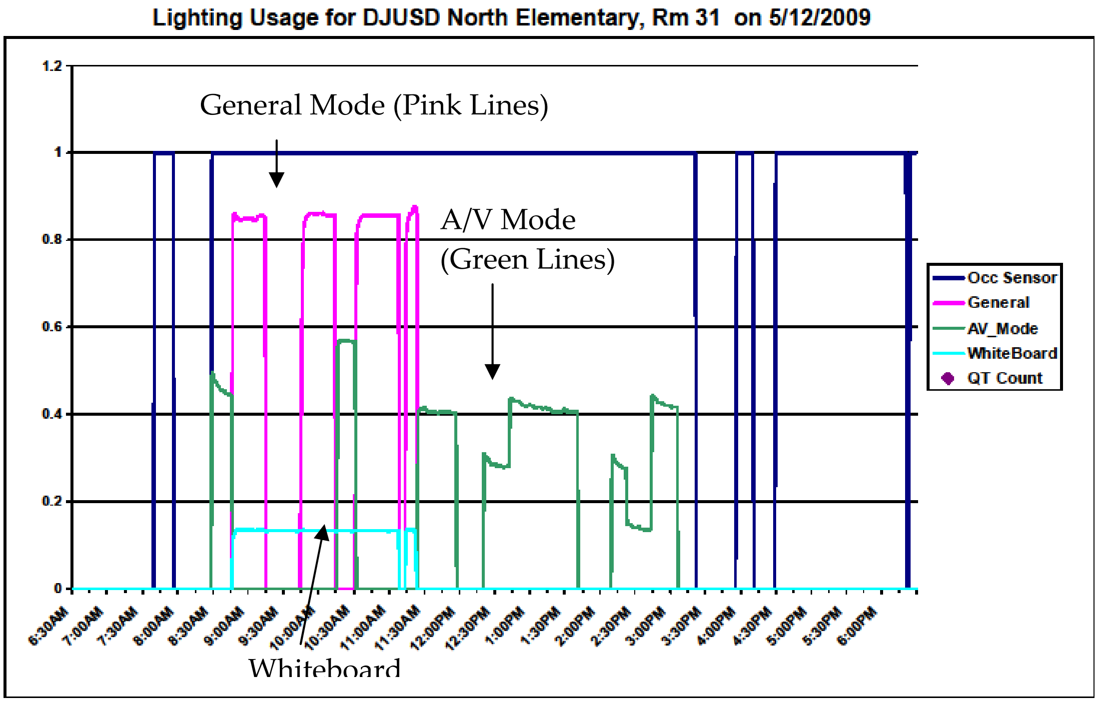


Figure 28: Visual Representation of System Usage for R-ICLS "Best-Recessed" for Same Classroom on May 28, 2009

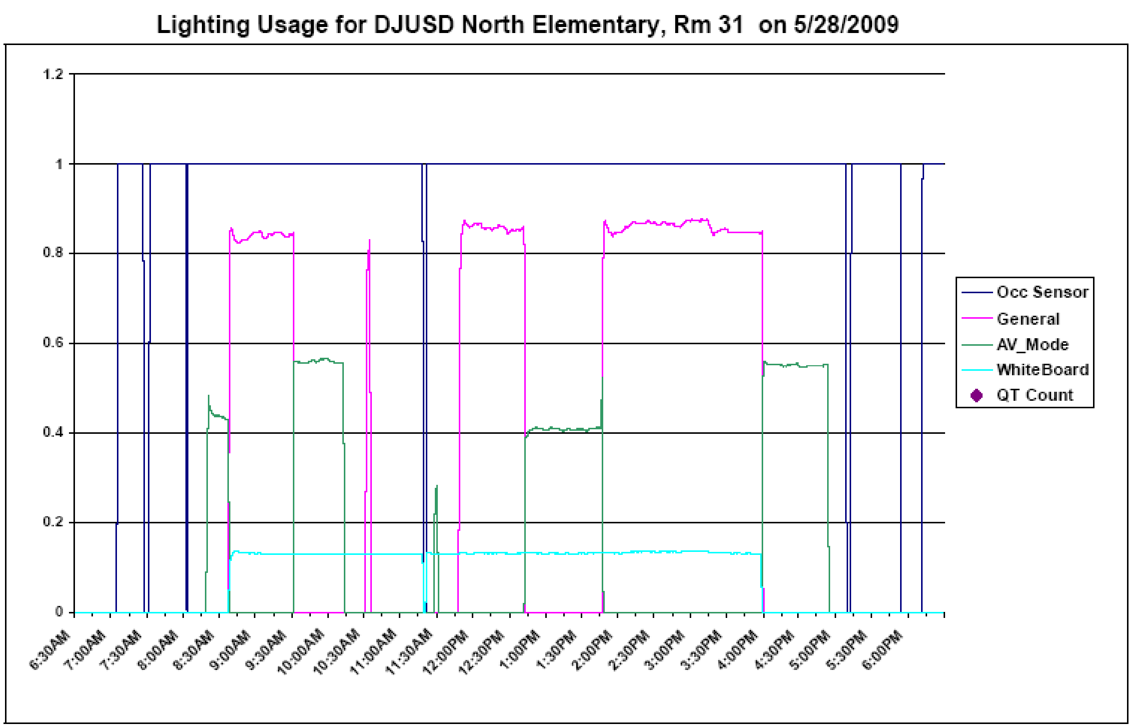
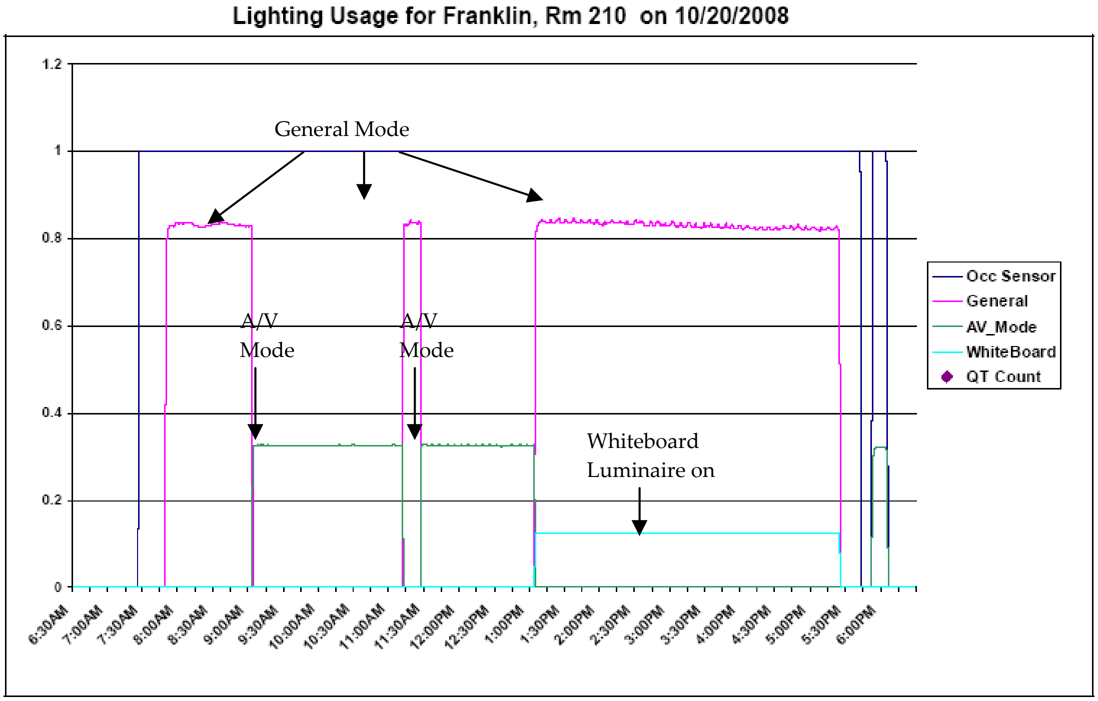


Figure 29: Visual Representation of System Usage in R-ICLS "Best-Pendant"



Classrooms need the flexibility of R-ICLS. The curriculum changes throughout the school year and the ability to switch between modes addresses this need. Figure 30 shows how one teacher changed how he/she used the lighting over the period of 39 days during the school year. In the beginning, the teacher used more General Mode. As the year progresses, the teacher used more A/V Mode as the curriculum warrants it.

Figure 30: Usage Data Showing How Teachers Use the System Differently as Curriculum Changes

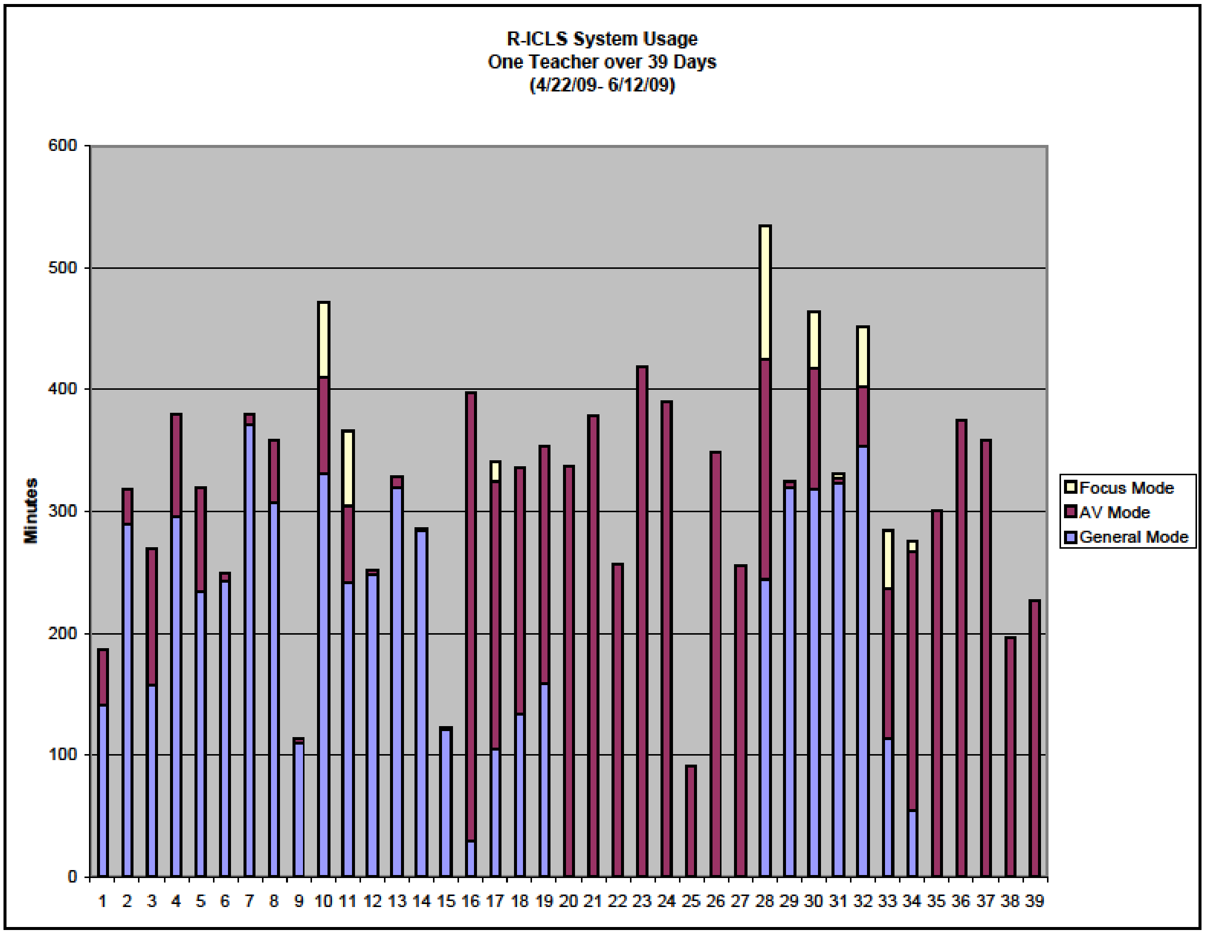
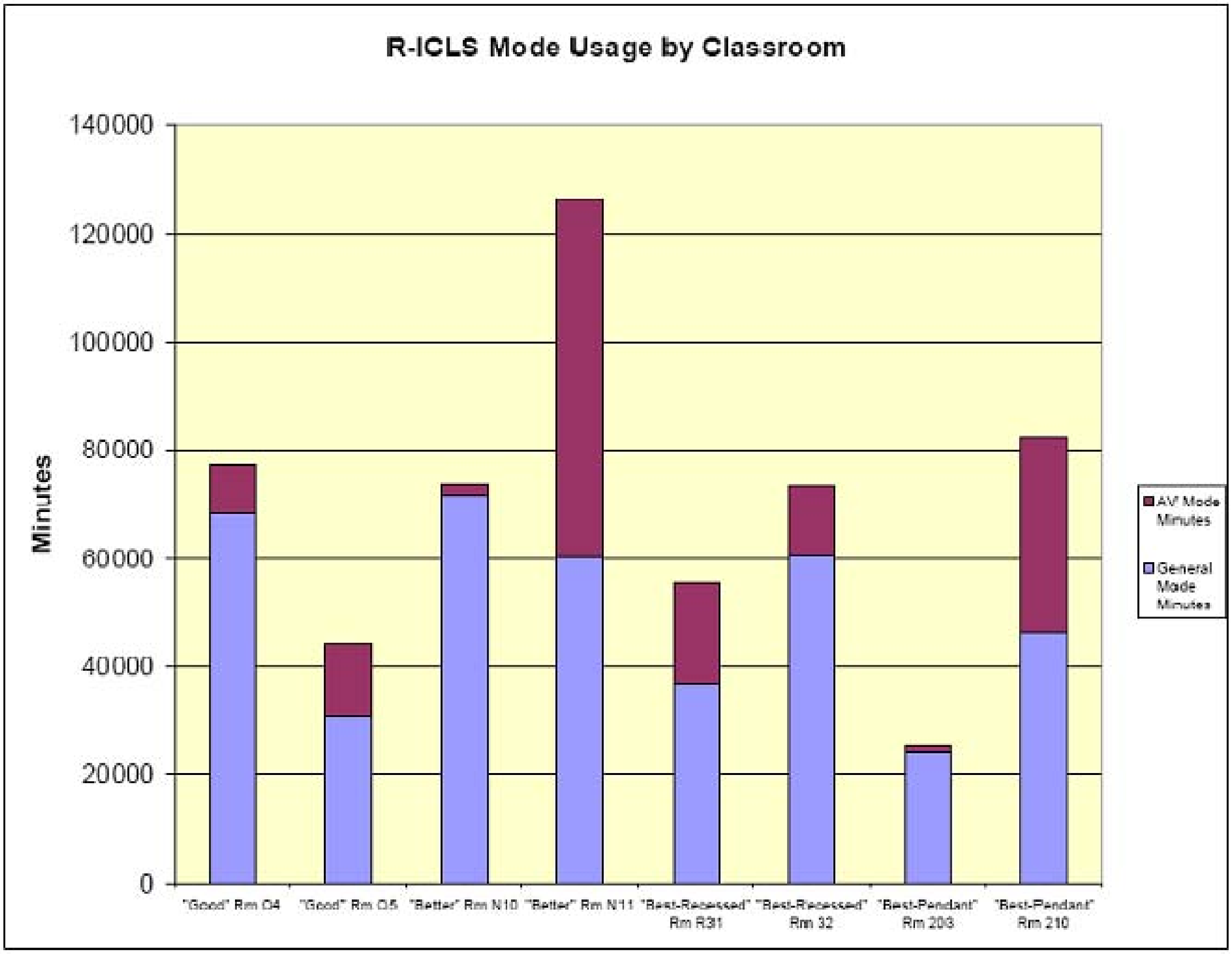


Figure 31 shows how the teachers used the different modes over the school year. On average, A/V Mode was used 25 percent of the time by teachers, with a high of 52 percent usage. It is important to note, A/V Mode was used differently by different teachers. Teachers appreciate the flexibility built into the system and can tailor the lighting levels to a specific teaching style.

Figure 31: Summary of Mode Usage by Teacher



6.1.9. Data Summary

As seen in Figure 32, the Data Summary chart incorporates all the data stored in the database to give a day-by-day review of the system usage for the R-ICLS test classrooms. The report details usage of each of the components. Days presented are restricted to periods where the system was used for more than 70 minutes, which helps exclude days of inactivity from the averages. Referencing, on 2/17/09, the teacher for Franklin Elementary, Classroom 210 switched into A/V Mode 6 times (A/V Use) for a total of 276 minutes (A/V Total Min). The average lighting power density was 0.58 (Watt/ ft^2) for the day with a total energy consumption of 4.38 kWh. Data summary sheets for the demonstration classrooms are shown in the Appendices.

Figure 32: Data Summary Chart

Data Summary

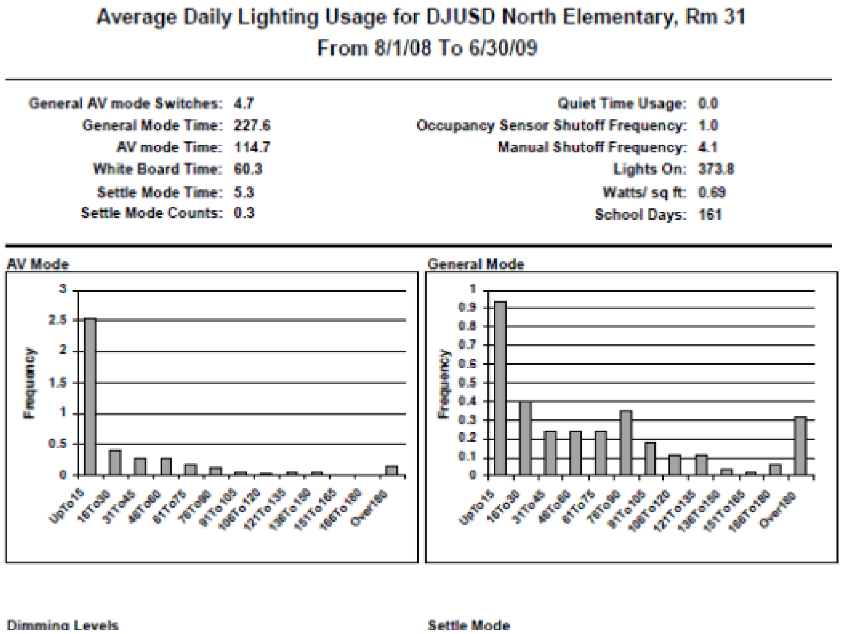
Franklin

Classroom	Date	AV Gen Switches	AV Use (#/Day)	WB Use (#/Day)	General Total Min	White Board Total Min	AV Total Min	Settle Time	Settle Count	Occ Sensor Shut Off	Manual Shut Off	Lights On Total	Watts/ sq ft	kWh
210	2/13/09	7	7	3	193	78	276	0		0	4	469	0.54	3.54
	2/17/09	9	6	5	232	230	311	0		0	3	543	0.58	4.38
	2/18/09	3	2	2	423	423	51	0		0	1	474	0.88	5.76
	2/19/09	5	3	3	272	165	147	0		0	3	419	0.69	4.02
	2/20/09	4	2	3	260	259	287	0		1	0	547	0.61	4.65
	2/21/09	1	1	3	97	54	14	0		2	1	111	0.81	1.25
	2/23/09	0	0	3	287	296	0	0		2	1	298	0.90	3.73
	2/24/09	6	3	4	331	289	117	0		0	2	448	0.77	4.77
	2/25/09	0	0	0	444	0	0	0		0	1	444	0.82	5.02
	2/26/09	0	0	0	408	0	0	0		2	4	408	0.82	4.61
	2/27/09	0	0	0	465	0	0	0		1	1	465	0.81	5.25
	2/28/09	0	0	0	257	0	0	0		2	2	257	0.81	2.87
	3/2/09	6	3	7	366	333	120	0		4	1	487	0.78	5.26
	3/3/09	9	6	4	160	155	287	0		0	2	447	0.53	3.30
	3/4/09	6	3	3	329	299	91	0		0	2	420	0.80	4.67
	3/5/09	7	5	3	307	165	291	0		1	1	598	0.61	5.06
	3/6/09	1	1	1	441	439	18	0		0	2	459	0.92	5.84
	3/9/09	5	3	2	217	108	326	0		3	1	543	0.54	4.08
	3/10/09	2	3	2	309	99	134	0		2	3	443	0.67	4.11

6.1.10. Average Daily Lighting Usage Report

The data captured can be summarized for each monitored classroom over a set period of time. Two primary sections are provided in Figure 33. The top section shows the average usage for the particular classroom over the set period of time (generally the entire school year). Average time spent in each of the modes is captured along with the number of switches between General and A/V Mode. Additionally, data such as average lighting power density is presented as well as the total number of school days. The bottom section of the report shows the average time spent in each of the modes plus the percent of dimming used when the system was in A/V dimming. Usage Reports for the demonstration classrooms are shown in the Appendices.

Figure 33: Daily Lighting Usage Chart



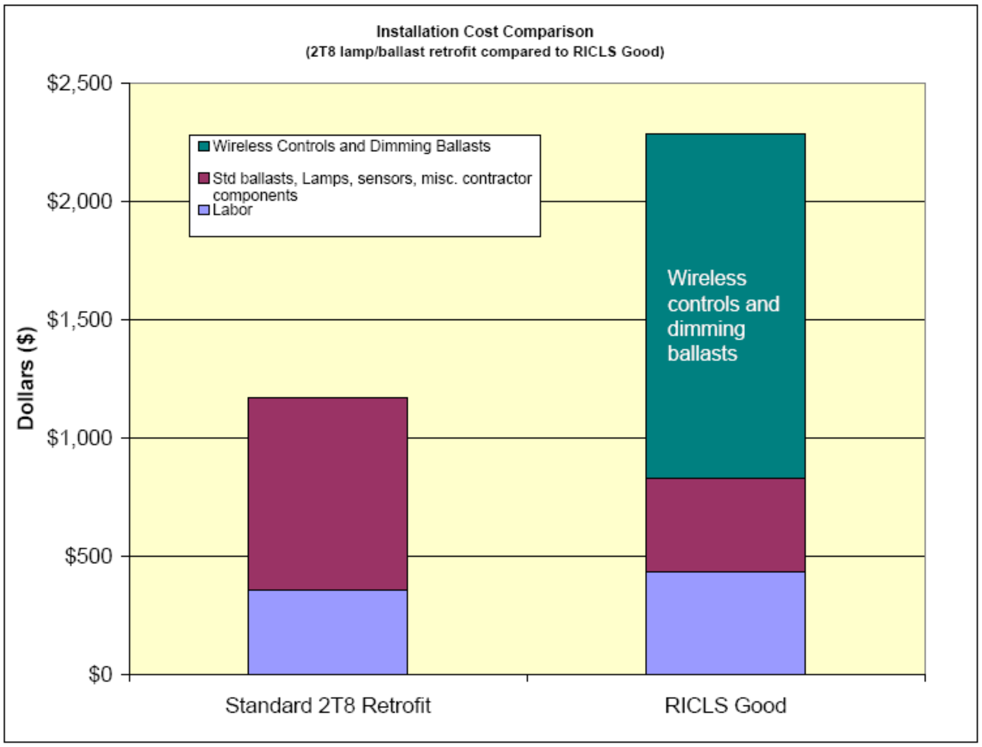
6.1.11. Material Cost Impacts

The data demonstrated that teachers prefer and use the R-ICLS system to provide an opportunity to improve the learning environment and reduce energy consumption. Achieving an A/V mode and giving teachers effective and accessible controls requires the use of dimming ballasts and wireless controls. The labor component of R-ICLS "Good", "Better", and "Best-Recessed" is very similar to what would be required to do a standard lamp/ballast retrofit. The major difference is the installation of a teacher control and the wireless control center. This is estimated to take an additional 1.5 hours.

The materials costs represent the major difference. Dimming ballasts and wireless controls make up 54 percent of the installed cost of "Good", 51 percent of the installed cost of "Better", and 22 percent of the installed cost of "Best." Overall, the driving factor in making R-ICLS viable to most school districts is finding ways to reduce the cost of dimming ballasts and wireless controls.

Figure 34 shows an installation cost comparison for a classroom using 2-T8 lamp/ballast retrofit compared to R-ICLS Good. Appendix C provides more detailed cost information.

Figure 34: Installation Cost Comparison



Simple paybacks for the R-ICLS options were calculated but found to not meet the original goals of the research project. The research team identified two key cost criteria required to make lighting retrofits viable for school districts: 1) $2,500 cost per classroom for R-ICLS and 2) $500 energy cost savings.

It is important to assess the existing conditions in a specific school site. LPD can vary greatly. Classrooms with extremely old or poorly designed lighting systems may exceed 2.0 W/ft^2. As previously mentioned in this report, ASHRAE standards mandate a maximum LPD of 1.4W/ft^2 (ASHRAE 90.1 – 2007) for classrooms. In California, the 2008 and 2013, Title 24 Building Energy Efficiency Code requires lighting power densities in new classrooms to not exceed 1.2 W/ft^2. LPD of the pre- and post-classrooms are a key factor in calculating the financial payback period.

6.1.12. Luminaire Research Outcomes

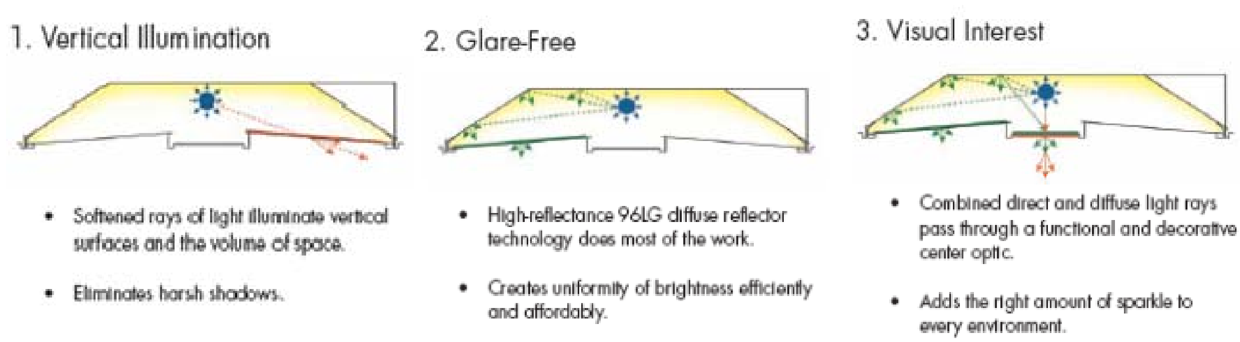
The research team reviewed luminaires available and decided it was necessary to develop a new luminaire to deliver performance at an affordable price. The luminaire, shown in Figure 35 was developed by Finelite. The luminaire yields high efficiency (87 percent with T8 and 97 percent with T5 lamps), high visual comfort levels. Appendix I includes technical sheets and a color brochure for this product.

Figure 35: Finelite HPR Luminaire

The luminaire optical design is shown in Figure 36. The most common configuration used in the classroom retrofit application is the 2x4 2-T8. The 2-T8 unit yields an efficiency of 84.8 percent with a spacing-to-mounting height of 1.4 feet.

The luminaire optical design delivers the lighting performance necessary to achieve low classroom lighting power densities 50 percent below the latest 2013 Title 24 Building Energy Efficiency Code. The luminaire puts light high on the walls removing shadows common to other recessed luminaire types, which makes the space more comfortable and functional.

Figure 36: Finelite HPR Optical Design



The project team used the AGI lighting photometric design software to test performance. Researchers evaluated the typical 30x32' classroom and found it can be illuminated with just nine 2-T8 2x4 luminaires as shown in Figure 37**Error! Reference source not found.**. This layout uses a whiteboard luminaire for additional vertical illumination on the whiteboard.

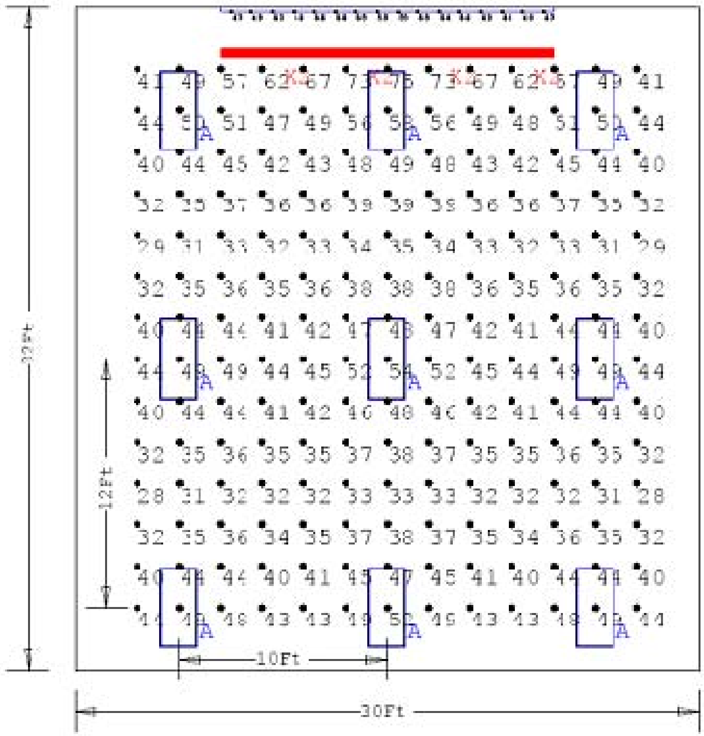
Average horizontal illumination: 43 fc

Average vertical illumination on the whiteboard: 50 fc

Lighting Power Density: 0.707 W/ft^2

Ballasts: 0.99 ballast factor instant start ballasts

Figure 37: Finelite HPR Luminaire Layout



CHAPTER 7:
Develop a Classroom Retrofit Guide

The Classroom Retrofit Guide provides today's decision makers with the information necessary to make the right choice for their classroom retrofit project. The brochure covers the reasons why a high performance retrofit is important for today's classroom environment, the costs associated with different strategies, and the templates necessary to achieve the results described in this project. The guide references project data including installation costs, energy savings, and teacher preferences.

The Classroom Retrofit Guide is contained in Appendix B. This tool can be used by school facility planners to select the right level of R-ICLS to meet specific lighting quality and payback goals.

CHAPTER 8:
Market Connection Activities

The project outcomes can be found at the PIER LCF website: www.archenergy.com/lcf.

CHAPTER 9: Project Outcomes

The standard lamp/ballast retrofit system yields energy savings. However, it offers no improvement to the performance of the classroom. The project team used the development process to identify issues and solutions associated with retrofitting typical classroom lighting. The product development effort also was guided by the standards for classroom lighting established by the U.S. Green Building Council's LEED and the Collaborative for High Performance School. .

Finelite and the CLTC surveyed the available technologies to achieve luminaire control with the following requirements: 1) eliminate the need to penetrate the ceiling; 2) eliminate the need to run excess electrical conduit or low voltage dimming lines; 3) controls could not be battery powered or hand-held remotes (not physically mounted to the wall); 4) the system will achieve an audiovisual (A/V) mode; 5) the system must be robust to accommodate the long life of educational facilities; and 6) the system developed must not cause interference between classrooms.

This project developed the following categories of systems to deliver energy savings, improve the lighting quality, address the needs of today's classrooms, and meet varying payback timelines. Each category builds upon the previous list of components.

- R-ICLS "Good" was developed to bring an A/V mode into the classroom environment to meet today's new teaching methodology without the need for additional wiring or ceiling supports.
  - Replace lamps and ballasts
  - Install Teacher Control Center
  - Install dual technology occupancy sensors
  - Use existing Master On/Off controls
  - Install Wireless Control Center
- R-ICLS "Better" was developed to do more than deliver an A/V mode. In previous studies focused on new construction and major remodels, adding whiteboard illumination yielded higher user preference and reduced energy consumption.
  - Add whiteboard luminaire
- R-ICLS "Best" was provided the highest quality option. In addition to adding A/V mode to the classroom, the R-ICLS "Best" replaced the luminaires with higher performing luminaires to deliver even greater quality and energy savings to the classroom.
  - Replace luminaires with high performance recessed luminaires or high performing pendant luminaires

Existing lighting systems were retrofitted in 13 classrooms in three schools in California. Three classrooms were "Good", three were "Better", three were "Best" using recessed luminaires, and four were "Best" using pendant luminaires. Initial conditions were recorded at each site. Installation costs were recorded to capture material and labor costs for each site. A data monitoring system recorded actual usage every minute of every day for a complete teaching year (3.2 million data points). The data recorded how the teachers used the system and the energy consumed over that school year.

Table 7 contains the pre-retrofit and post-retrofit power usage and power densities for each system. In the current 2013 Title 24 Building Energy Efficiency Code, the power density for classrooms is 1.1 W/ ft^2 for the Complete Building method and 1.2 W/ ft^2 for the Area Category method. In ANSI/ASHRAE/IESNA[13] Standard 90.1-2007, the lighting power density for classrooms is 1.2 W/ ft^2 for the Building Area method and 1.4 W/ ft^2 for the Space-by-Space method.

The Good-Recessed, Best-Recessed, and Best-Pendant systems had power density reductions of 53 percent, 54 percent, and 79 percent, respectively. The pre-retrofit lighting power densities were higher than code at 1.55, 1.92, and 4.26, and the post-retrofit lighting power densities were lower than code at 0.73, 0.89, and 0.88.

The Better-Recessed system had a power density increase of 14 percent. The pre-retrofit lighting power density, 1.18 W/ ft^2, met code requirements while the post-retrofit lighting power density, 1.35 W/ ft^2, does not meet the latest code requirements. The power density increase is due to the addition of the whiteboard luminaire, the fact that not all of the pre-retrofit lamps and ballasts were working, and the dimmable ballasts installed consume slightly more wattage than the electronic T8 ballasts they replaced.

Table 7: Actual Lighting Power and Lighting Power Densities

School	Davis Senior High	Davis Senior High	North Davis Elementary	Franklin Elementary
System Type	**Good-Recessed**	**Better-Recessed**	**Best-Recessed**	**Best-Pendant**
Pre-Retrofit Power (W)	1,488	1,062	1,728	3,544
Pre-Retrofit Power Density (W/ ft^2.)	1.55	1.18	1.92	4.26
Post-Retrofit Connected Power (W)	696	1,212	796	735
Post-Retrofit Power Density (W/ ft^2)	0.73	1.35	0.89	0.88
Retrofit Power Savings (%)	53%	-14%	54%	79%

Simple paybacks based on the R-ICLS demonstrations are calculated below in Table 8 but found to not meet the original goals of the research project. The simple payback ranges from 8.9 to 23.6 years. The payback is based an energy rate of $0.128. The Davis High School "Better-Recessed"

13 Acronyms for American National Standards Institute, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, and Illuminating Engineering Society of North America.

system shows no payback because of the increase in energy use. The research team identified two key cost criteria required to make lighting retrofits viable for school districts (payback less than 5 years: 1) $2,500 cost per classroom for R-ICLS and 2) $500 energy cost savings.

To improve the payback, other lighting areas such as corridors, offices and gymnasiums within the school may have to be included. These areas provide additional opportunities for energy savings and could be packaged together to provide better paybacks.

Table 8: Simple Payback Analysis from R-ICLS Demonstration Sites

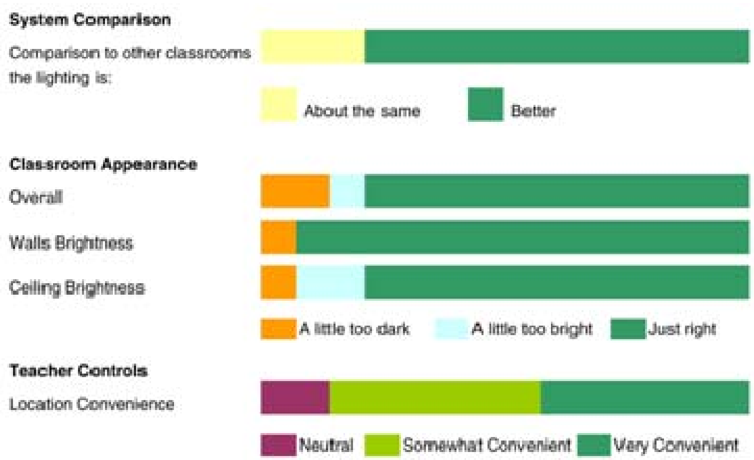
School	Davis High	Davis High	Davis Elementary	Franklin Elementary
R-ICLS Payback Analysis	**Good-Recessed**	**Better-Recessed**	**Best-Recessed**	**Best-Pendant**
Power Savings (watts)	792	(150)	932	2,809
Student Days per year	180	180	180	180
Student Hours per day	10	10	10	10
Non-Student Days per year	20	20	20	20
Non-Student Hours per day	4	4	4	4
Energy Rate ($/kWh)	$ 0.128	$ 0.128	$ 0.128	$ 0.128
Energy Savings ($/yr)	$ 191	$ (36)	$ 224	$ 676
Cost (material + labor)*	$ 2,200.00	$ 4,100.00	$ 5,300.00	$ 6,000.00
Payback (years)	11.5	N/A	23.6	8.9

Note: Parentheses indicate a net increase in power usage and increase in cost.
* Actual materials and labor costs

The research team reviewed luminaires available and decided it was necessary to develop a new luminaire to deliver performance at an affordable price. The High Performance Recess (HPR) product was developed by Finelite, during this project.

Teachers were interviewed by researchers and completed questionnaires with respect to qualitative aspects of the retrofit alternatives. Teachers readily accept R-ICLS with an A/V mode. Also, the majority of teachers surveyed felt the R-ICLS system was better than previous systems used. No teachers reported the previous lighting was better than R-ICLS. Teachers surveyed found the lighting comfortable even with lighting levels being reduced and found location and usage of the teacher controls to be convenient. Figure 38 shows the teacher survey results for this project.

Figure 38: Teacher Survey Results



A Classroom Retrofit Guide was developed by Finelite as part of this project (Appendix B). The brochure covers the reasons why a high performance retrofit is important for today's classroom environment, the costs associated with different strategies, and the templates necessary to achieve the results described in this project. The guide references project data including installation costs, energy savings, and teacher preferences.

CHAPTER 10: Conclusions and Recommendations

10.1. Conclusions

Existing luminaires in the classroom drive the retrofit decision. Retrofit projects minimize costs by reducing construction labor and materials. The budget does not accommodate rebuilding space, rewiring, or adding additional ceiling supports. Replacing existing luminaires with those of similar form factor ensures the existing supports and electrical feeds can be used, drastically reducing installation costs. The R-ICLS options address the two most common fixture types used in classrooms: recessed 2x4 and suspended linear fluorescent luminaires.

The research evaluated three categories of retrofit solutions (Good, Better, and Best).

- R-ICLS "Good" is viable for recessed luminaire projects. The project evaluated and found the "Good" level was not viable for pendant luminaires as the unique configurations of pendant luminaires would lead to higher than acceptable labor costs to rewire.
- R-ICLS "Better" was not found to be viable for either recessed or pendant classrooms. The inability to change luminaire layouts in the recessed application leads to higher light levels, which decreases the importance of the whiteboard luminaire. The added cost and added power of the whiteboard luminaire also increases the payback timelines beyond acceptable limits. "Better" pendant range is not viable for the same reasons as the "Good".
- R-ICLS "Best" is viable for both recessed and pendant applications. Lighting quality is improved by replacing existing recessed luminaires one-for-one with high performance luminaires, or changing the pendant luminaires and layout. This is a great solution for schools that want to improve lighting quality and energy efficiency at costs significantly below major remodels.

Retrofitting pendant luminaires requires a different strategy than recessed luminaires due to the unique construction and layout of pendant systems. Older design philosophy and luminaire efficiency led to using more luminaires than necessary. Today's luminaires are much more efficient and two rows of luminaires can now provide what previously took three rows. The wiring of pendant luminaires impacts luminaire design making "Good" and "Better" options not viable. The pendant retrofit decision is either simply replace the lamps with lower wattage T8 lamps or change out the luminaires. Changing luminaire layouts dramatically improves the lighting quality and yields the greatest energy savings. R-ICLS "Best-Pendant" replaced three rows of T12 direct/indirect luminaires with 2 rows of efficient direct/indirect luminaires.

Figure 39: Pre-Retrofit Classroom with 3 Rows of T12 Pendant Luminaires

Figure 40: Post-Retrofit with 2 Rows of T8 Indirect/Direct Luminaires with a Whiteboard Luminaire

High performance retrofit classrooms emphasize an A/V mode and teacher controls at the front of the classroom. It is critical for classroom lighting retrofits to give instructors a lighting mode that improves the contrast and effectiveness of A/V presentations used to instruct and engage students. The placement of teacher controls is equally important. Controls placed at the front of the classroom provide more teacher control and opportunities to save energy. Missing the opportunity to update the classroom during a retrofit project reduces the overall effectiveness of the classroom for years.

Other conclusions drawn from this project are strong teacher preference for classroom lighting with A/V mode and controls for A/V mode located at the front of the classroom. Also, energy savings can be achieved with excellent user acceptance.

Despite significant power and energy savings, the R-ICLS system cost remains prohibitive, with simple paybacks exceeding the typical windows that many school districts need. Labor and materials costs are the two factors that must be considered. For material costs, the driving factor in making R-ICLS viable for more districts is reducing the cost of dimming ballasts and wireless controls. When compared to a traditional lamp/ballast retrofit, significant incremental expenses for R-ICLS are for the dimming ballasts and wireless controls.

It also is important to factor in the economy of scale as efficiency gains can be realized in larger projects. If an entire building, school, or district were to be retrofitted, the install cost would be less because of the contractor's learning curve.

10.2. Recommendations

The research team has identified two key cost criteria that must be met to achieve viable paybacks for school districts: 1) $2,500 labor and material cost per classroom for R-ICLS and 2) $500 annual energy cost savings. School retrofits eliminating high LPDs or T12 classroom lighting, volume pricing for R-ICLS options, and efficiency labor gains are critical to meeting these cost parameters. Scheduling is an important part of installation cost containment, taking place when schools are not in session.

Retrofitting lighting in additional areas such as corridors and gymnasiums could increase energy savings and allow schools to take advantage of economy of scale and gains in labor efficiency, resulting in more tenable payback periods.

The manufacturing partner will continue to evaluate the design and system configuration to develop cost-effective classroom retrofit solutions. The R-ICLS options provide a great visual environment and user flexibility in a system that is environment friendly and LEED/CHPS friendly.

More demonstrations of the R-ICLS with the above recommended changes would better define viable retrofits.

GLOSSARY

Specific terms and acronyms used throughout this work statement are defined as follows:

Acronym	Definition
AEC	Architectural Energy Corporation
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
A/V	Audiovisual
CCT	Correlated color temperature
Commission	California Energy Commission
CFL	Compact fluorescent lights
CHPS	California High Performance Schools
CLTC	California Lighting Technology Center
CRI	Color rendering index
CSU	California State University
DR	Demand response
FC	Footcandles
GWh	Gigawatt Hours
ICLS	Integrated Classroom Lighting System
LCF	Lighting California's Future
LEED	Leadership in Energy and Environmental Design
IESNA	Illuminating Engineering Society of North America
LPD	Lighting power density
LRP	Lighting Research Program
kW	Kilowatt
kWh	Kilowatt-hour
M&V	Measurement and verification
MLS	Milliamps
MW	Megawatt
MWh	Megawatt hour

Acronym	Definition
N/A	Not available
NYSERDA	New York State Energy Research and Development Authority
IOU	Investor-owned utility
M&V	Monitoring and Verification
PIER	Public Interest Energy Research
R-ICLS	Retrofit-Integrated Classroom Lighting System
SMUD	Sacramento Municipal Utility District
TCC	Teacher Control Center
Title 24	California Non-Residential Energy Efficiency Building Standards
TOU	Time of use (electricity rate)
UCC.1	Uniform Commercial Code (Financing Statement)
Vdc	Volts direct current
W	Watts
W/ft^2	Watts per square foot