LIGHTING RESEARCH PROGRAM

Project 4.5 Integrated Classroom Lighting System
FINAL REPORT

CONSULTANT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Arnold Schwarzenegger, *Governor*

October 2005
CEC-500-2005-141-A14

CALIFORNIA ENERGY COMMISSION

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ACKNOWLEDGEMENTS

The products and outcomes presented in this report are a result of funding provided by the California Energy Commission's Public Interest Energy Research (PIER) program on behalf of the citizens of California. Architectural Energy Corporation and Finelite Inc. would like to acknowledge the support and contributions of the individuals below:

Project Lead: Terry Clark, Finelite Inc.

Technical and Marketing Assistance: Marc McMillan, Doug Bourne, Jane White, Buen Guido, Finelite Inc.; Rick Miller, RNM Engineering Inc.; Nancy Clanton, Clanton and Associates; Jim Benya, Benya Lighting; Christine Magar and Gregg Ander, Southern California Edison; Jack Rollow, Los Angeles Unified School District (LAUSD); Doug Paton and Jerry Mix, The Watt Stopper; Don Aumann, California Lighting Technology Center (CLTC); George Loisos, Loisos + Ubbelohde; and countless others who assisted with the installation of the ICLS at the various California classrooms.

Element 4 Lead: John Kesselring

Element 4 Technical Advisory Group: Jerry Mills, Easy Lite; Jeremy Bloom, EPRI; David Shiller, EPA.

Program Advisory Committee: Ron Lewis, Department of Energy; Jerry Mills, Easy Lite; Gregg Ander, SCE; Bill Daiber, WFD Associates; James Bryan, Arden Realty; Neall Digert, Solatube; Jim Benya, Benya Lighting; Dennis Tiede, Sempra Utilities; Noah Horowitz, NRDC; Amy Cortese, Northwest Energy Efficiency Alliance; Pekka Hakkarainen, Lutron; Peter Turnbull, PG&E; Michael Waxer, Carmel Development Co; Kit Tuveson, Tuveson & Associates; David Kaneda, Integrated Design Associates, Inc; Connie Buchan, SMUD.

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PREFACE

The 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, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:
• Buildings End-Use Energy Efficiency
• Industrial/Agricultural/Water End-Use Energy Efficiency
• Renewable Energy
• Environmentally-Preferred Advanced Generation
• Energy-Related Environmental Research
• Strategic Energy Research

What follows is the final report for the Integrated Classroom Lighting System (ICLS) Project, PIER Lighting Research Program Contract #500-01-041, conducted by Finelite Inc. and directed by Architectural Energy Corporation. This project contributes to the Building End-Use Energy Efficiency program.

The key deliverables for each project, in the form of guidelines and technical reports, are attachments to this report and are listed and described at the start of the attachment section. Due to market dynamics and the normal passage of time between the completion of research and the publication of research results, products anticipated for market delivery in this report may not necessarily reflect the actual array of products as delivered, or planned for delivery, by manufacturers. Therefore, the reader is advised to contact the lighting product manufacturers directly to ascertain the current status of products.

For more information on the PIER Program, please visit the Commission's Web site at: www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

ABSTRACT

With input from representatives of the Collaborative for High Performance Schools (CHPS), Finelite Inc. used a combination of best practices and new technologies to develop and test an integrated classroom lighting system (ICLS) for K-12 classrooms. The basic system includes indirect luminaires with energy efficient T-8 lamps and electronic ballast, 96% reflective material within the fixture, a teacher control center located at the front of the classroom, and plug-and-play components.

Working with six California schools, variations of the ICLS were installed in 19 classrooms. Researchers continuously monitored the ICLS and other baseline classrooms for one school year and analyzed the resulting data. The data shows a 30 to 50% reduction in energy use in the ICLS classrooms, with improved lighting on the teaching walls and better flexibility for adjusting light levels during audio/visual presentations. The ICLS also provides approximately 40 to 50 footcandles (fc) of light on student's desks while maintaining less then one watt per square foot (0.9 W/sq.ft.) in the classrooms. 2005 Title-24 codes require schools to have 1.2 W/sq.ft. or less in new classrooms. Teachers were also surveyed and provided positive responses to the light levels and the quality of light in the classrooms. A derivative project that involved installing a hybrid ICLS in a daylit training classroom was also completed.

The ICLS provides quality lighting and is an economical alternative to typical classroom lighting designs and, to help minimize support and warranty costs, is bundled as a package system with one source of responsibility.

EXECUTIVE SUMMARY

Lighting typically represents 20% of the total energy use in a K-12 school. By reducing the connected lighting load and giving teachers more control of the lighting system, significant energy savings can be realized while providing a higher quality of light.

The Integrated Classroom Lighting System (ICLS), PIER LRP Project 4.5, was a two and a half-year research and development effort focused on developing a lighting system that was energy efficient, provided high quality lighting and control flexibility, yet was affordable and easy to install and maintain. The project had tremendous collaboration and followed a rigorous methodology.

With input from representatives of the Collaborative for High Performance Schools (CHPS), Finelite Inc. used a combination of best practices and new technologies to develop and test an integrated classroom lighting system (ICLS) for K-12 classrooms. The basic system includes indirect luminaires with energy efficient T-8 lamps and electronic ballast, 96% reflective material within the fixture, a teacher control center located at the front of the classroom, and plug-and-play components.

Working with six California schools, variations of the ICLS were installed in 19 classrooms. Figure 1 provides an example of the existing lighting system and the new ICLS. Researchers continuously monitored the ICLS and other baseline classrooms for one school year and analyzed the resulting data. The data shows a 30 to 50 percent reduction in energy use in the ICLS classrooms over typical lighting systems with improved lighting on the teaching walls and better flexibility for adjusting light levels during audio/visual presentations. The ICLS also provides approximately 40 to 70 footcandles (fc) of light on student's desks while maintaining less then one watt per square foot (0.9 W/sq.ft..) in the classrooms. 2005 Title-24 codes require schools to have 1.2 W/sq.ft. or less in new classrooms. Teachers were also surveyed and provided positive responses to the quality of light in the classrooms.

Figure 1: Existing Lighting System (1.8 W/sq.ft.) and New ICLS System (.8 W/sq.ft.)

Researchers then installed a hybrid ICLS in a Southern California Edison (SCE) training classroom, which is designed to take advantage of daylighting. Light level measurements were taken to verify the ICLS performance in daylit environments. The hybrid system was demonstrated to several lighting specifiers and customers, and feedback obtained.

Key results from the ICLS project include:

- Reduced energy usage by 30 to 50 percent
- Lower lighting power densities (LPDs) which are 20% less than new 2005 Title 24 levels (reference Figure 2)
- Improved flexibility for setting light levels for general teaching and audio-visual (A/V) presentations
- Perceived reduction in eye strain and glare and improved quality of light by teachers
- Documented ICLS component and installation costs
- Integration of ICLS with daylight in a harmonious and energy efficient manner

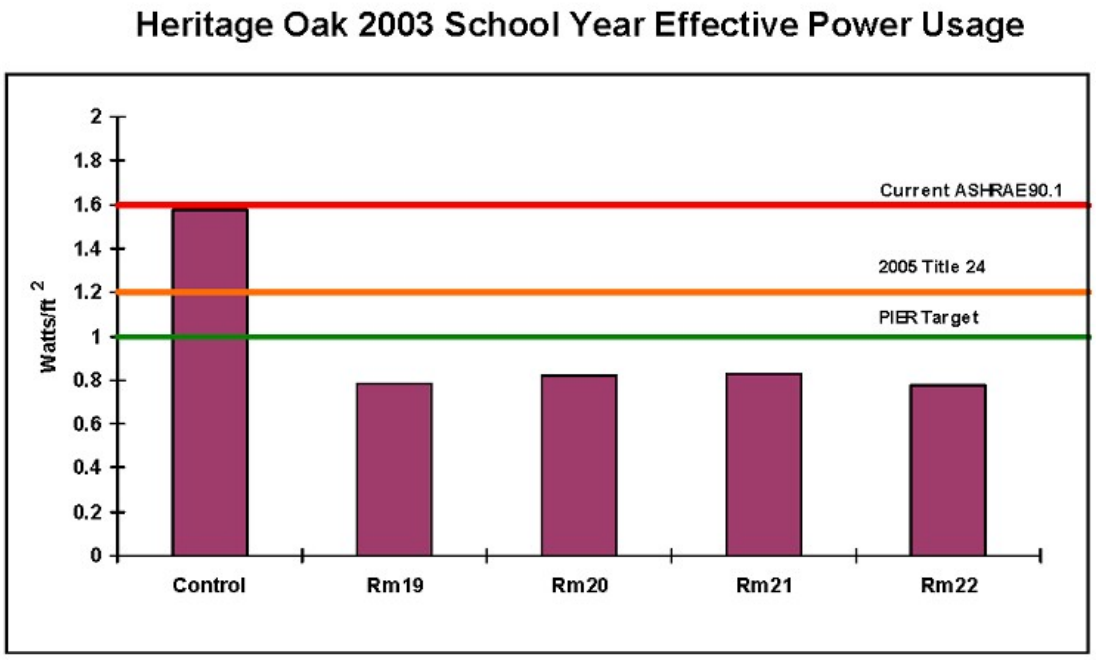


Figure 2: Lighting Power Density (LPD) for four of the ICLS test classrooms shows approximately .8 W/sq.ft. as compared to ASHRAE 90.1 and 2005 Title 24 standards.

Key features of the ICLS include:

- High performance, pendant-hung indirect luminaires
- Easy-to-use teacher controls located at the front of the classroom
- Dual technology occupancy sensors with a teacher-controlled time delay
- Low-voltage, plug-and-play interconnection cables to tie the system together
- Optional photosensors for daylit environments
- Single-source “system” responsibility for layout, pricing, commissioning, and warranty to ensure that budgets are met and savings are obtained

Teachers, principals, school administrators, facility managers, energy managers, architects, engineers, lighting specifiers, project managers, and general and electrical contractors should benefit from the documented and quantified results of the PIER LRP Project 4.5 ICLS. The results, which demonstrated dramatic energy savings, combined with strong teacher preference for the ICLS, may also help school districts, and local, state, and federal governments set more aggressive energy efficiency standards and policies.

Over the last two years, Finelite Inc. and other PIER LRP participants provided presentations highlighting the results of this project to numerous schools districts, lighting designers, utility representatives, and other interested audiences. However, work still needs to be done to build awareness in the teaching, design, and construction communities. These communities need to be aware that the benefits and energy efficiency of the ICLS are documented, the system is available for today's classrooms, is reasonably priced, and the quality of lighting is exemplary.

INTRODUCTION

Background

Developing and documenting more energy efficient and cost effective ways to light K-12 classrooms meets the PIER goal of improving the energy cost and value of California's electricity because of the following reasons:

- Lighting in classrooms may potentially impact the rate of learning for over 6 million students attending K-12 classes in California. Lighting whiteboards, teaching walls, students' and teachers' desks, and teachers' faces is fundamental to the learning process.
- California spends approximately $3 billion per year on school improvements. Building schools requires coordination among school administrators and teachers, and their architects, engineers, construction managers, and contractors. Making these parties aware that it is time to change from old, out-of-date lighting systems to new, more effective ones is a major challenge.
- Installing improved, up-to-date lighting systems is a cost-effective way to spend school construction dollars. Nevertheless, many decision-makers believe they cannot afford quality indirect lighting because they rely on inaccurate or out-of-date cost estimates or advice.
- New energy-efficient indirect lighting systems can reduce lighting loads by almost 20% from the new 2005 Title 24 levels. Cutting energy waste in classroom lighting reduces operating expenses for the school.
- The current building boom in schools creates an opportunity to ensure that effective classroom lighting systems are installed. However, since classrooms do not go through regular updates or remodels, missing this window of opportunity means up to a 30 to 40 year wait for the next chance to improve a particular school's classroom lighting.

New methods of learning and other factors affect the way classrooms should be lighted. These changes mean that old, proven ways to light classrooms are obsolete. Some of the factors that have changed with respect to classroom lighting are:

- Classrooms are becoming computerized environments. Schools are installing cable and fiber networks in over 99% of all new classrooms. Classrooms need glare-free lighting systems with proper light levels for computer use. Indirect lighting, used in the ICLS, is recommended for lighting classrooms by both the Illuminating Engineering Society of North America (IESNA) in their publication RP-3 and by the Collaborative for High Performance Schools (CHPS) in their training materials.
- Classrooms are becoming A/V centers. New curriculums are beginning to include more web-based and DVD-based instruction materials. Use of overhead and computer-based projectors and televisions to display materials means teachers need to be able to change the lighting from General mode (light on the teaching walls and ceiling) to an A/V mode (limited lighting on the walls and ceiling) at the touch of a switch. Research indicates that teachers need to be able to do this in an easy manner, which does not disrupt the class, or they will not do it. Adding an A/V lighting mode option to a lighting system needs to be affordable and energy-efficient.

- More schools are incorporating daylighting into classrooms. This means that the classroom lighting system must be flexible and able to adjust to different daylight conditions. Adding automated dimming options to a lighting system also needs to be affordable and energy-efficient.
- New technology delivers better lighting at lower costs. Examples include:

    - Indirect luminaires with new 96% reflective materials can deliver more light onto the workplane and are up to 15% more efficient than older luminaires
    - 3100 lumen "Super" T8 lamps are 10% more efficient and provide better color rendering than standard T8 lamps
    - New T8 electronic ballasts with 1.2 ballast factors (BF) allow two lamps to perform the work of three without reducing lamp life or performance
    - New occupancy sensors and controls let teachers reduce annoying and disruptive false luminaire shut-offs during tests or other "Quiet Time" periods
    - New plug-and-play interconnection systems reduce installation costs to help meet today's tight budget requirements

Project Goals and Objectives

The goals of the PIER LRP Project 4.5 were to use new technologies to build a high-performance, cost-effective integrated lighting system, to verify system performance and teacher acceptance in actual California classrooms, and educate school districts, the design and construction communities, and others about the results. Specific objectives for the ICLS were:

- Use high-efficiency indirect luminaires to light the teacher's face, the walls, and the desks while at the same time cutting glare in the classroom.
- Demonstrate that 2 rows of indirect luminaires can be used instead of the 3-row system originally recommended by CHPS. (It should be noted in this report that the term "indirect luminaire" is used to describe luminaires with a lighting distribution that ranges from 90% uplight and 10% downlight to as much as 67% uplight and 33% downlight. Other reference materials may call some of these luminaires indirect/direct or even direct/indirect luminaires.)
- Provide effective lighting options for A/V presentations. With this option, there is less light on the walls and ceiling to produce veiling reflections. However, there is still adequate illuminance on the student's desk for note taking.
- Keep installed costs affordable to meet budget requirements. System options should be priced separately so design teams for each school can easily match benefits to cost.
- Operate at a maximum connected load of less than 1.0 W/sq.ft. Savings due to time in A/V mode and automatic shut off of the lights by the occupancy sensor should lead to an additional 10-20% reduction from the maximum level. This means that the average energy usage should be around .8 W/sq.ft.
- Build a robust ICLS. Recognize the potential for student abuse and meet or exceed seismic requirements.
- Utilize plug-and-play interconnections between sensors and controls to help ensure correct, cost-effective installation and problem diagnostic and resolution.
- Provide ICLS layout, pricing, delivery, and field support from a single-source manufacturer.

Project Methodology

Finelite used the following research methodology to meet the project's goals and objectives. Throughout the project, Finelite staff communicated with representatives from CHPS, SCE, AEC, Clanton and Associates, BKi, LAUSD, and the California State Architect's office to understand best practices, design, installation, and maintenance issues, and codes and standard implications.

Step 1: Review best practices including new reflector materials, T8 and T5HO lamps, electronic ballasts with different ballast factors, sensors, and controls.

Step 2: Design a system using components that would become commercially available by early 2005.

Step 3: Build a 28 x 30-foot classroom with 10-foot-high ceilings. Furnish it with desks and chairs to provide a test area for the project. Install the initial ICLS system in the test classroom and verify its performance. Improve the system based on feedback from lighting professionals.

Step 4: Work with 6 schools to identify "test" classrooms to receive the ICLS. Install different versions of the ICLS in the test classrooms.

Step 5: Use an independent consultant (Rick Miller) to document performance (light levels, energy loads, and teacher preference). Record energy usage 24 hours a day, seven days a week for an entire teaching year. Develop, distribute, and collect questionnaires to get teacher feedback on the ICLS performance. Summarize findings to show savings and preferences.

Step 6: Make additional ICLS adjustments and enhancements to incorporate feedback from the teachers, facilities managers, school administrators, and lighting specifiers who visited the test ICLS classrooms.

Step 7: Install a hybrid ICLS system at the SCE daylit classroom that includes a dedicated, cost-effective whiteboard luminaire in a classroom and document its performance under different daylight and teaching conditions.

Step 8: Educate school districts, the design and construction communities, and others about the results.

Step 9: Produce a final report with findings and supporting documentation.

PROJECT OUTCOMES

Project 4.5 research and development activities led to a number of significant findings. This section summarizes the key outcomes.

96% Reflective Material Technical Data

The first key outcome was the development and testing of the 96 percent reflective material that is used in the ICLS luminaire. A summary of the test results is provided below.

Background

Every time light reflects off of a surface a portion is absorbed or "lost." Since light often bounces multiple times within a fixture before it is directed outward, the amount of light that is lost can become substantial very quickly. Table 1 shows how an increase in reflectivity from 86% to 97% generates 62% more light output after only four reflections.

Material type	Reflectivity	Formula for 4 reflections	Efficiency after 4 reflections	% Increase
White, pre-painted steel (standard quality)	86%	.86 x .86 x .86 x .86	55%	Base case
Desired white reflective material	97%	.97 x .97 x .97 x .97	89%	+ 62%

Table 1: Reflectivity and efficiency comparisons of white pre-painted steel versus new white reflective material.

Despite its relatively poor optical performance, white pre-painted steel is used for most luminaires because it is widely available from numerous sources and it is cheap. Currently available materials with high reflectance have limitations that make them difficult to use in an affordable classroom lighting fixtures. A summary of materials and issues associated with them are listed below in Table 2.

Material	Reflectivity	Issues
Pre-painted white aluminum	90%	About twice as expensive as pre-painted steel.
Specular aluminum and metalized films	95%	About four times as expensive as pre-painted steel. Maybe vulnerable to scratches. Specular (mirror) finishes can cause glare.
Gortex™	97%	Very expensive. Many times more expensive than pre-painted steel.

Material	Reflectivity	Issues
		Specialty material.
AOT paint	97%	Good high-temperature characteristics, difficult to apply on large surfaces. Moderately expensive

Table 2: Summary of the potential luminaire material and issues.

Several years ago, the Filled and Reinforced Plastics Division of FERRO Corporation's Specialty Plastics Group was approached to develop a high-reflectance material. (For the balance of the report, we will refer to this Division as "FERRO.") As a result of that request, FERRO undertook an extensive development program to formulate a 97% reflective plastic material that was suitable for injection molding. That development program was a success. The final result was a new, custom plastic that achieved over 97% reflectivity and that was easy to injection mold.

The focus of the first task under Project 4.5 was to evaluate how this material would perform as a component of a new classroom luminaire. Specifically, researchers wanted to work with FERRO to determine what modifications, if any, would be needed to the original material. Once the modifications were determined, Finelite wanted to explore the impact of those modifications on the reflectivity and the cost of the material.

Criteria for Performance Evaluation

Finelite began by developing the criteria that would be used to evaluate the characteristics of the new material. From a lighting manufacturer's perspective, seven areas were identified that needed to be examined. For each area, performance targets were set. These areas and performance targets are listed below:

1. **Reflective Performance**
   We set our target for the material to be 97% reflective. This target was established based on the results of a series of discussion between Finelite and FERRO. The primary issue was that the cost of the new material varied with targeted reflectivity. Finelite found that as reflectivity became higher, the cost of the material also increased. Accordingly, 97% was selected as a target that would be a suitable balance between our drive for low material cost versus high performance.

2. **Cost**
   Our target was to achieve superior performance while keeping the cost premium less than 20% compared to parts made from PVC plastic (about 84% reflective) or pre-painted steel (about 86% reflective). We focused on the final part cost rather than material costs in order to allow for different manufacturing processes required for steel versus plastic parts.

3. **UV Stability**

We set a goal of no visible yellowing after close exposure to fluorescent lamps for a period of 10 years. In scientific terms, this translated to a goal of a delta b* and delta E* shift of less than 3 units under accelerated UV testing.

4. **Flammability**
   We set the goal to meet or exceed the standard UL-94 V2 set by Underwriter Laboratories™. By meeting this standard, we would ensure that any part made with this material would be "self extinguishing" within 250 seconds. (This is measured from the time the source of combustion is removed). This ensures that the luminaire would not spread a fire from one part of the classroom to another.

5. **Temperature stability and mechanical strength**
   We set our temperature stability target at 140 degrees Fahrenheit (this is the temperature that a part might experience while being shipped or stored in a closed container in 105 degree weather.) The strength should be sufficient to meet all UL requirements and to stand up to potential classroom abuse.

6. **Molding and extrusion parameters**
   We approached this point by working with a vendor that currently provides injection molded plastic parts to Finelite. Our criteria was to run tests using actual material to ensure that all parameters of the new material would be suitable for his equipment and run on our normal dies.

7. **Availability**
   The final material developed must be able to be formulated on FERRO's existing lines. And, it needs to be relatively "risk free" in our ability to move from pilot production quantities to higher-volume production. Due to its custom formulation, we did not set the criteria to have more than one supplier for the material.

Performance Results

Below is a summary of the results for each area:

1. Reflectance – Achieved 97% reflectivity.
2. Cost – Appropriate for special parts at production quantities.
3. UV Stability – Verified this is very stable material.
4. Flammability – Passed UL 94 - V2 rating criteria.
5. Temperature stability and mechanical properties – Met most goals.
6. Molding parameters – Successfully made parts with existing dies.
7. Availability – Verified material is available.

The custom material that was evaluated is part number NPP00RT5678WH made by FERRO Corporation – Specialty Plastics Group, Filled and Reinforced Plastics Division. The description of this plastic is " HIGHLY REFLECTIVE, UV STABELIZED, FLAME RETARDANT POLYPROPYLENE WITH AN IN-HOUSE UL94 RATING OF V-2 @ 1/16"."

Conclusion

The 5678 WH material evaluated by Finelite looks like a very good candidate for use in a more efficient classroom luminaire. This new material offers the potential to develop more efficient reflector systems that can still meet the cost constraints imposed by the educational market. By using more efficient reflectors, classroom lighting fixtures can be made to deliver the same level of desk-level illumination in the classroom with less electrical power. Accordingly, this new plastic material is an enabling technology that helps the State of California accomplish its goal of reducing energy usage.

Further, this material seems to have uses for making reflectors for emerging technologies such as LEDs. FERRO's willingness to work with manufacturers to optimize the formula for their unique needs will help further speed the development of luminaires that bring this new technology to market.

Generic Classroom Lighting Specification

Another key outcome of this project is the development of a classroom lighting specification based on the ICLS for use by school districts, lighting specifiers, and lighting contractors. The ICLS specification is provided in Appendix A and may be included as part of any Section 16500 Specifications for classroom lighting.

The ICLS combines a high performance, direct-indirect luminaire with three high-efficiency Super T8 lamps. General-purpose classroom illumination (~0.95 W/sq.ft.) is achieved using 2 of the 3 lamps in the direct-indirect lighting fixture producing approximately 75 percent up-light and 25 %t down-light. An appropriate light level (~40 to 70 fc) is maintained on the student's desk. An Audio/Video (A/V) or reading mode provides 3 % up-light and 97 % downlight using only a single down-light with optional dimming to 5 % output. In the A/V mode, light levels on the ceiling and walls are reduced while an appropriate light level (~30 fc) is maintained on the student's desk.

Energy and Cost Savings

Energy Savings

One of the major outcomes of this project is the documented energy savings. Daily energy savings ranged from a minimum of 35% to a maximum of 75%, and averaged over 50% for the entire year for the ICLS installations. Most of the savings (~80%) were the result of the reduction in the connected lighting load from 1.8 to 1.0 W/sf. Additional savings (~20%) were the result of allowing teachers more control of the lighting system and providing occupancy sensors.

One of the test sites, Heritage Oaks School in Roseville, had the ICLS installed in four classrooms. The daily energy savings are clearly demonstrated in Figure 3 for all of the ICLS rooms. The base case at Heritage Oaks was 2X4 lay-in troffers with T-8 lamps. Four variations of the ICLS were installed: 2 rows of ICLS lighting; 2 rows of ICLS lighting with manual

dimming on the teacher control center; 3 rows of ICLS lighting; 3 rows of ICLS lighting with manual dimming on the teacher control center.

Graphs representing the LPDs for all six schools, the energy data collection methodology, and an example of the resulting data are shown in Appendix B. Appendix C provides the light levels, LPDs, and installed system information for each of the test classrooms.

The actual monitored data from the test classrooms, which was taken in one minute intervals for the entire 2003/2004 school year and includes more than 10 million data points, is available for download and review at www.archenergy.com/lrp/products/classroom.htm. The file size of the data is extremely large approaching close to 100 MB.

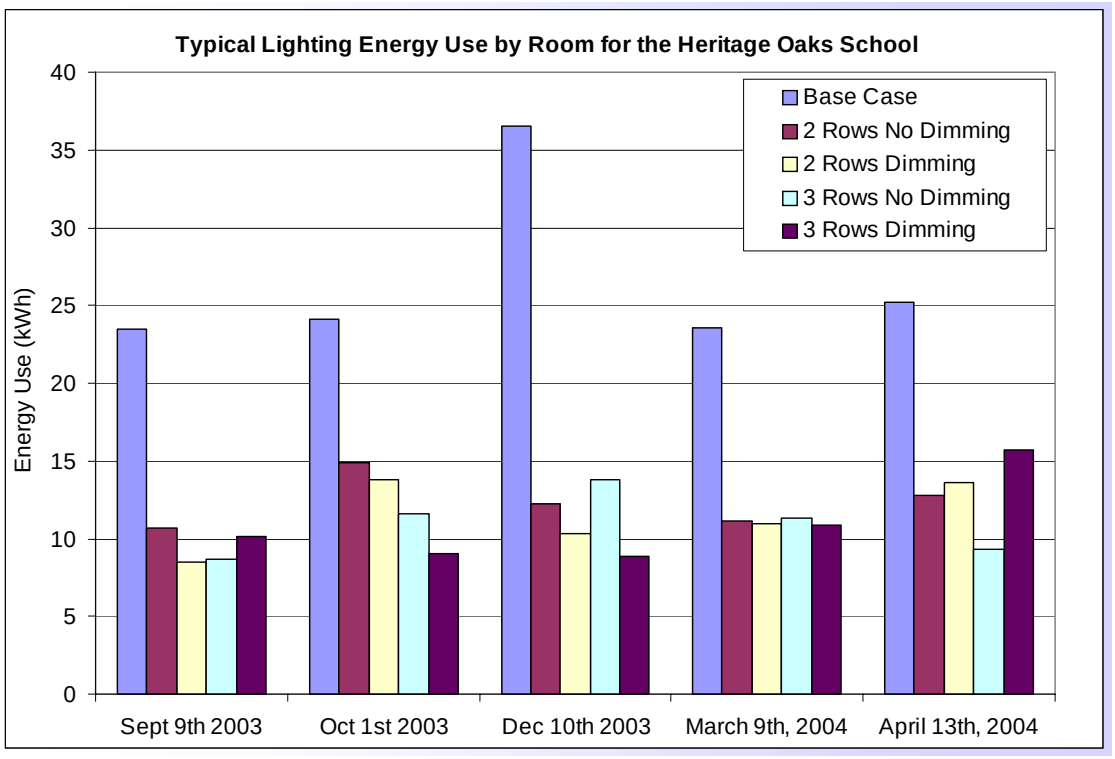


Figure 3: ICLS energy use compared to a lensed troffer lighting system. Energy savings vary seasonally. Greatest savings were realized during the winter.

Cost Savings

The cost of the classroom retrofits at Heritage Oaks was $2600 for the two-row without dimming and approximately $3100 with A/V dimming control. The third row of luminaires cost an additional $1100. The ICLS retrofit using occupancy sensors resulted in energy savings averaging more than 50%, which, based on 7 months, of data translate into nearly $500 savings annually per room ($0.14/kWh, 200 days per year). The resulting payback period was a minimum of 6.5 years for two rows of luminaires and a maximum of 9.6 years for three rows with A/V dimming control. The information is summarized in Table 3.

Heritage Oaks School Retrofit Payback Period						
	Average Daily Use (kWh)	Estimated Annual Use (kWh)	Estimated Annual Cost ($)	Estimated Annual Savings ($)	Initial Cost ($)	**Retrofit Payback (yrs)**
Base Case (26 Parabolics)	26.6	5318	$745	$0	$0	**--**
ICLS 2 Rows, No A/V Dim*	12.3	2469	$346	$399	$2,600	**6.5**
ICLS 2 Rows, with A/V Dim*	11.4	2284	$320	$425	$3,100	**7.3**
ICLS 3 Rows, No A/V Dim*	11.0	2191	$307	$438	$3,700	**8.4**
ICLS 3 Rows, with A/V Dim*	10.9	2185	$306	$439	$4,200	**9.6**

* Includes Occupancy Sensor

Table 3: Summary of the energy and cost savings for the various lighting configurations at the Heritage Oaks School, one of the schools that was retrofitted.

For new construction, the installed cost of the ICLS (~$2.71 / sq ft) is less than the cost of a typical layout using 15 parabolic troffers (~$2.86 / sq ft.). The maximum connected load for the ICLS is approximately 0.95 W/sq. ft. compared to 1.35 W/sq. ft. for more typical designs. The reduced lighting load combined with no additional first cost yields an instant payback. Installing the optional upgrade of A/V dimming still results in a payback of 2 years while a third row of luminaires has a longer payback (8.1 years), assuming $0.14/kWh and 200 days/yr.

New Construction Estimated Payback Period						
Alternative	LPD (W/sq ft)	Installed Cost ($/sq ft)	Installed Cost ($)	Cost Difference ($)	Cost Savings ($/yr)	Simple Payback (yrs)
15 Parabolics (typical)	1.35	$2.86	$2,745	$0	$0	--
ICLS 2 Rows, No A/V Dim*	**0.93**	**$2.71**	**$2,600**	**-$145**	**$106**	**Instant!**
ICLS 2 Rows, with A/V Dim*	0.73	$3.23	$3,100	$355	$176	2.0
ICLS 3 Rows, No A/V Dim*	0.95	$3.86	$3,700	$955	$118	8.1
ICLS 3 Rows, with A/V Dim*	0.75	$4.38	$4,200	$1,455	$168	8.6

* Includes Occupancy Sensor

Table 4: Summary of the LPD, cost, and savings for new construction using the four variations of the ICLS as compared to a typical classroom lighting system.

Teacher Acceptability and Feedback

Teachers at each of the 6 schools were surveyed and provided valuable feedback to the researchers and the manufacturers about the system. Overall, the teachers preferred the ICLS to typical classroom lighting systems. Some teachers expressed the comment that they did not realize the poor quality of light from the typical classroom lighting systems (which were 2X4 lay-in troffers with T-8 lamps and on/off switches located only at the room entryway) until the ICLS was installed. This comment indicates that teachers and school administrators need to be educated about the importance of the quality of light in the classroom. The teacher surveys provided other useful information about the acceptability of the ICLS and a summary report is provided in Appendix D.

One issue identified from the surveys was the need for a “Quiet” time switch, which allows the teachers to disable the occupancy sensor for one hour during test times or reading periods. This feature eliminates the lights turning off when students and teachers are in the room, but not active. The development of the “Quiet” time switch, see Figure 4, is a key outcome.

In addition, a high-performance dedicated whiteboard luminaire was developed and will be introduced in 2005 to provide more light on the main teaching wall. Some teachers had expressed a concern about the light levels at the teacher’s desk and on the teaching wall. The addition of the whiteboard luminaire alleviates this issue.

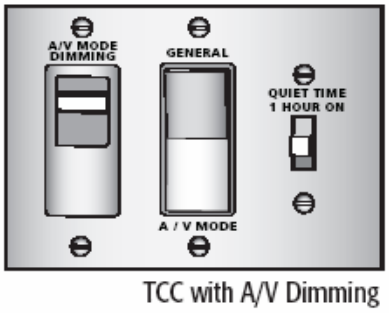
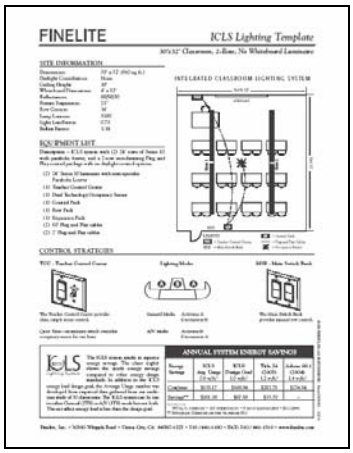


Figure 4: A “Quiet” time switch option was added to the Teacher Control Center as a result of teacher feedback to increase the acceptability of the ICLS.

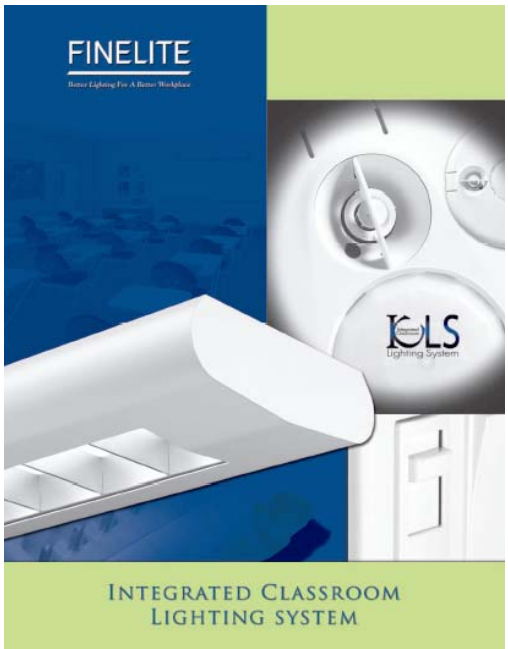
ICLS Templates and Manufacturer Literature Development

Templates based on the ICLS were developed, which provide visual and easy to read guides for lighting specifiers and school personnel. The following four scenarios were developed and are provided in Appendix E.

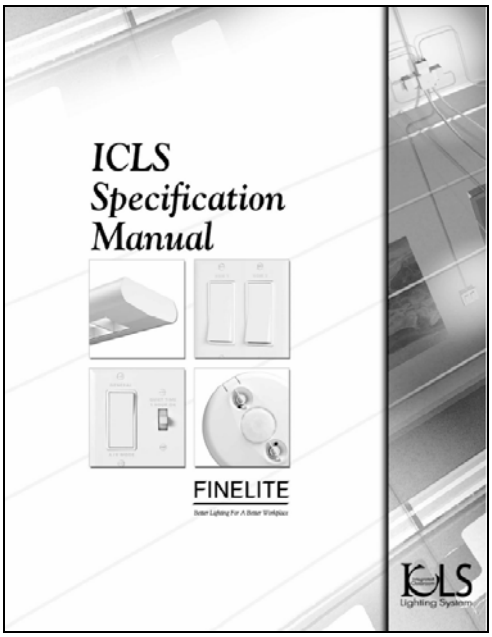


- 30′x32′ Classroom, 2-Row, No Whiteboard Luminaire
- 30′x32′ Classroom, 2-Row, With Whiteboard Luminaire
- 28′x28′ Classroom, 2-Row, No Whiteboard Luminaire
- 28′x28′ Classroom, 2-Row, With Whiteboard Luminaire

Literature was also developed by the manufacturer and includes the following: the ICLS brochure, a specification manual that describes the major components and features of the system, and a use and care manual.



ICLS Brochure



ICLS Specification Manual

ICLS Use and Care Manual

Copies of the literature are provided in Appendix F. A PIER Project 4.5 brochure and case study were also developed and are available at www.archenergy.com/lrp/products/classroom.htm.

TECHNICAL RECOMMENDATIONS

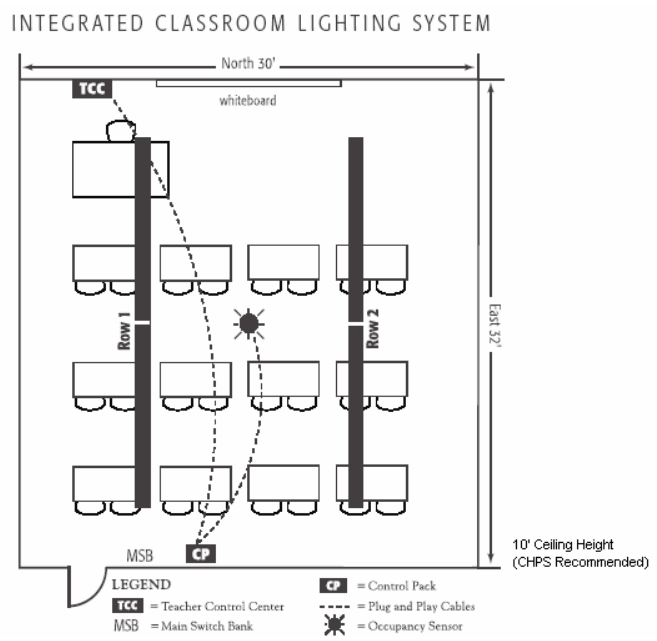
Based on the project results, several technical recommendations follow.

Use indirect luminaires to light the classroom. Prices for these luminaires have decreased over the last several years and their energy efficiency has increased. It is now possible to use these high quality, recommended luminaires in K-12 classrooms.

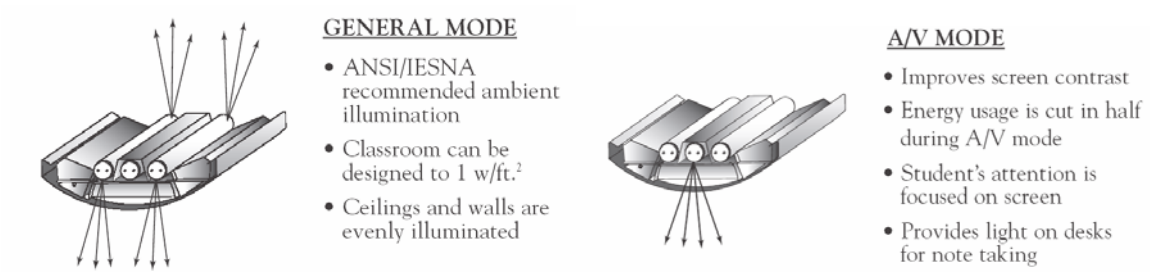
Indirect Luminaire

- ICLS uses indirect luminaires to deliver expert recommended lighting quality.
- Glare is eliminated for fewer classroom distractions
- Walls and ceilings are evenly illuminated
- High reflectance materials ensure optimum efficiency.

Light a 32 x 30-foot classroom with two 24-foot rows of indirect suspended luminaires. The indirect luminaire should use two 3100-lumen T8 lamps, in cross section, in an uplight mode to light the ceiling, walls, desks, and teacher's face uniformly and without glare. The maximum connected load of this system will be under 1- W/sq. ft.; this will occur when the luminaires are in the General Mode with all rows turned on. Use 1.2 ballast factor electronic T8 ballasts in this system to provide an average of over 60 fc with a 4 to 1 uniformity across the students' desks. For lower light levels or different sized rooms, use electronic T8 ballasts with .88 BF, .77 BF, or even .71 BF electronic T8 ballasts to keep the maximum connected load equal to or less than 1 W/sq. ft..

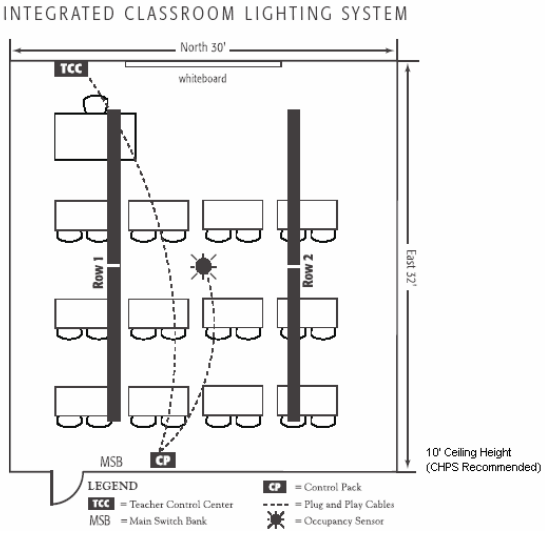


Use the indirect luminaire to create an A/V lighting mode in classrooms. While this is primarily used during A/V presentations, teachers also used this mode to calm students and to help them focus on tasks on their desks like silent reading or individual problem solving. Over 99% of new California classrooms are being wired for Internet access to accommodate more web-based learning tools. Manufacturers of textbooks are also planning on more DVD-based instruction materials. This means that during the useful life of the classroom, it may become a space where A/V presentations are used many times a day. The recommended, cost-effective way to provide an A/V mode of lighting is to use an indirect luminaire with a separate downlight compartment. The teacher uses a switch located at the front of the classroom to change from General to A/V mode. The switch has an interlock mechanism to ensure that all three lamps are not on at one time. This ensures that the maximum load never exceeds 1 watt per square foot.



Place a Teacher Control Center (TCC) at the front of the classroom. This is where the switch to control the mode of lighting (General or A/V) is located along with controls for other options and features. It is important for the teacher to control the system without losing eye contact with students. Teachers tend not to use control switches when they were located next to the door. In these cases, they turned on all the lights and left them on for the entire teaching day.

In contrast, when the TCC was located in the front of the classroom, the teacher used the TCC nearly every day and often used it several times a day to enhance the teaching environment.



Teacher Control Center

Provide ways to control the light levels based on the amount of daylight in the classroom. The system should use a separate switch for each row of luminaires. This provides manual on/off control of the row of lights parallel to the windows. Automatic on/off row switching or automatic dimming based on daylight should be explored and evaluated based on overall design objectives. Blinds should be used in classrooms with substantial daylight to ensure proper light levels are achieved during A/V presentations.

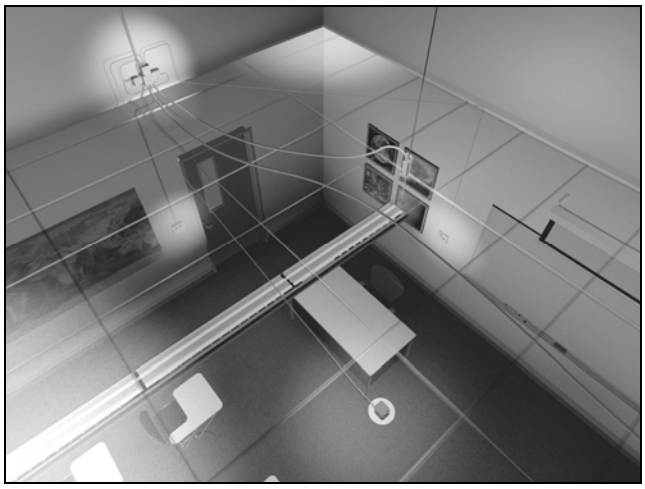
Row Control (Main Switch Bank)

Use occupancy sensors that combine dual sensor technologies and a teacher-controlled delay that keeps the lights on for a longer period of time during tests and other quiet periods. The nature of the classroom is unique. Generally, sensor delays should be kept short to maximize savings (reduce energy waste) during recesses, lunch periods, or whenever the teacher is away from the classroom, and other non-occupied periods. However, the delay needs to be sufficiently long to avoid false luminaire shut-offs during tests and other quiet periods. The results of Project 4.5 indicate that this is best done by a simple teacher control at the front of the classroom that allows the teacher to change the delay. A toggle switch located in the TCC is used to change the delay from its normal 10-minute setting to 1-hour. Each time the toggle is pushed, the delay is re-set to a full hour. This lets the teacher participate in cutting waste while, at the same time, ensure that the class is not disrupted during tests or other quiet periods.

Dual Technology Occupancy Sensor

Teacher Control Center w/ Quiet Time

Select a system that uses plug-and-play interconnection cables between the controls and sensors. This approach will help ensure that initial installation costs remain within existing construction budgets. Plug-and-play interconnections reduce system life-cycle costs due to simplified troubleshooting and maintenance procedures.



Low Voltage Plug together wiring

Specify a system that has a single manufacturer as the point of support for applications, pricing, and field support. The nature of the ICLS is sufficiently complex that it will benefit the school district to work with one manufacturer. This will help ensure that the system is priced properly and that training can be delivered to teachers through a well-constructed “Use and Care” manual. Additionally, the maintenance and facility groups in the school district will only have to make one call for support and technical training.

Select a system that has flexibility. For example, look for easy addition of a second occupancy sensor in a particular room or a whiteboard-specific luminaire.

Evaluate adding the ability to dim the T8 lamp in the A/V mode. This is a cost-effective way to let the teacher reduce the light in the classroom; it also increases the contrast of the material on the A/V screen. This works with simple overhead projectors and with sophisticated PC-based

projector systems. The controls should be at the front of the classroom and should be clearly labeled so substitute teachers can operate the system without the need to scroll though different scenes.

Keep the entire system simple and easy to use. Positive teacher preference resulted from three things: increased control, a user-friendly interface, and better-quality indirect lighting.

INTEGRATED CLASSROOM LIGHTING SYSTEM COMPONENTS

The following components make up the ICLS that was developed in Project 4.5.

- Luminaires:
    i. An indirect luminaire with an optical system utilizing new 96% reflective materials was selected to provide general lighting in the classroom. The actual luminaire installed in the test classrooms was Finelite's Series 10-PLV-3T8-DC-EP-CCO-277volts-FA-FE. Information on this luminaire, including its photometric performance, can be found at www.finelite.com.
    ii. A/V mode was accomplished by using a 3-lamp cross section where the center lamp is in a separate optical compartment. This allows for separate "General" and "A/V" mode operation. Two other systems for providing A/V modes have been explored:
        1. The first is dimming all the lamps in the luminaire. When all the lamps are on full output, the classroom is lighted in the General mode. When the lamps are dimmed, veiling reflections are reduced and the room is in an A/V mode. We did not make this our "standard" configuration for a number of reasons. First, this approach is significantly more expensive than the luminaire that uses a separate optical compartment for the A/V mode. Second, dimming ballasts carry a 10% to 20% energy penalty when compared to instant-start T8 ballasts. Third, while we understand that a number of manufacturers are testing a 1.2 BF T8 dimming ballast, none of these ballasts were commercially available during the test period. Using standard, readily available .9 BF T8 or 1.0 BF T5HO dimming ballasts, may not provide sufficient illuminance levels for some customers. Nevertheless, if dimming ballasts are needed for another reason, such as working with a closed-loop daylight dimming system, the dimming ballasts will provide a very adequate A/V mode.
        2. The second approach is to use a switching scheme that turns off lamps in the row of luminaires closest to the main teaching wall and leaves them on at the back of the classroom. (This approach is presented as Example 1 in Classroom Lighting Guidelines developed by Southern California Edison. These can be found at www.sce.com.) This system has the advantage that it uses a luminaire with 2-T8 lamps in cross section and may have a lower installed cost than even the recommended base system. However, the desk-level illuminance is not as uniform as with a dedicated A/V lamp in a separate compartment. Accordingly, for the relatively modest added cost for T8 ballasts and lamps, we felt that the more uniform lighting would provide a greater benefit over the years of use.
    iii. 3150 lumen 3500 K T8 lamps were used in the ICLS. T8 lamps were selected over T5HO lamps in the base system for a number of reasons. These included:
        1. While in the A/V mode, a dedicated downward directed T5HO lamp provides too much illuminance in the classroom. (Desk-level

illuminance would be around 80 fc in A/V mode.) Using standard T5 lamps instead of T5HO would address this issue. However, the T5 system costs substantially more than a T8 system and does not provide substantial benefits. Since schools would prefer to avoid mixing lamp types in a luminaire, using a T8 lamp for A/V mode strongly suggests that T8 lamps should be used throughout the luminaire.

2. Information from the US Department of Energy shows that T8 lamps and ballasts actually have a higher end of life lumen maintenance level than a T5HO system. Therefore, using T8 lamps is the most energy efficient approach.
3. There are four different ballast factors for T8 lamps versus one for the T5HO system. This means that a design team can change ballast factors with a T8 system to address various room dimensions and still keep the total luminaire connected energy load under 1 W/sq. ft..
4. The potential to make a slightly more efficient luminaire by using T5HO or T5 lamps instead of T8 does not offset the three disadvantages identified above.
5. The study selected 3500 K lamps based on a recommendation from consultants to the CHPS program. Some districts may prefer to use 4100 K lamps of even higher temperatures that bring into play Photopic and Scotopic considerations. An extensive study of how lamp temperature impacts students was outside the scope of this study.

iv. 1.18 BF instant-start electronic T8 ballasts were selected for the base system. Reasons that instant-start ballasts were selected included:

1. Currently, there is no 1.18 BF program-start ballast generally available. Accordingly, if the school wants to target an average of 50 to 60 maintained foot-candles and use a 2-row system, the only ballast that delivers this performance is a 1.18 BF instant-start T8. If a school has substantial daylight in the classrooms and is willing to accept maintained light levels of 35 to 40 fc, then this could be accomplished by using either .88 BF instant start or .88 BF program-start ballasts. However, based on the points below, instant-start ballasts would still seem to be a better choice.
2. Instant-start ballasts are generally less expensive and consume less energy than program start ballasts. This means they save on initial installation costs and on-going energy costs.
3. Program-start ballasts have a 1- to 2-second delay after the switch is turned on until the lamps turn on. While this is not noticeable in many applications, it is noticeable when changing between General and A/V mode. Since user acceptance is a major point in developing ICLS, we wanted to go with the fastest change possible between modes.
4. Our data showed that the class was in A/V mode about one to two times a day. To project how this impacts lamp life, we needed to make several assumptions. One is that we felt, in relatively short order, use of the A/V mode would increase to 4 times a day. That means the downlight-A/V lamps would switch on and off 4 times a day. At short

switching cycles, T8 lamps will turn on and off approximately 4,000 times (Source: OSRAM and GE). This means that the A/V-mode lamps would last approximately 1,000 days (4,000 cycles divided by 4 cycles per day). At 200 days per school year, this is a 5-year lamp life. This was judged acceptable to the specifiers and school facility managers we contacted.

5. However, T8 lamps will last close to their full rated life of 26,000 hours on a 3-hour switching cycle (source OSRAM). when used with program-start ballasts and occupancy sensors. In schools where it is very expensive to replace a lamp, the advantage of a 20-year lamp life might offset the disadvantage of using more energy. (26,000 hours T8 lamp life, 6 hours a day in general mode, 200 days of school each year equals a 21.7 year projected lamp life for the lamps used in the general mode. The A/V lamp that operates for only a couple hours a day would last for nearly 60 years.) Each school district will need to review this tradeoff between increased energy usage and lower lamp replacement costs.

v. Parabolic louvers were selected to provide shielding for the downward lighting component. Parabolic louvers provide good shielding that reduces glare and have the advantage of being “open.” This means that objects will fall right through the luminaire and there is less light depreciation due to dirt and contamination. On the other hand, different shields are available that may provide a better fit with needs such as a bright look in laboratories or a soft perforated look. However, when perforated luminaires are selected, the school should consider a dust cover to keep debris out of the luminaire. This adds cost and decreases luminaire efficiency by as much as 10%; however, it will keep the luminaires looking better for years.

vi. Aircraft cable pendant supports were used. Standard 1/16th inch galvanized aircraft cables with a rated load of 450 pounds per support were used in the test classrooms. Aircraft cables capable of over 900 pounds per support are generally available for a modest added cost. We experienced no issues in the test classrooms; however, the maximum load requirement is best set at a school district level. We examined swivel stems that combine a steel stem with a ball at one end that is captured in a steel bracket. We rejected this support mechanism due to seismic concerns. On the surface, it would seem that steel supports would be superior. However, the swivel stems only rotate 45-degrees in any direction. Once they hit the stop, there is no specification as to the loads they can take before the ball dislocates from the socket. Investigations at actual earthquake sites found instances where the stem and ball did separate from the socket and the fixtures fell. Fixtures on aircraft cables do not have this problem. In fact, a number of years ago the City of Los Angeles maintained a testing laboratory that had an earthquake simulator capable of generating the shaking of a 9.0 magnitude earthquake. The 1/16th-inch aircraft cables were able to support the indirect luminaires during this test. Accordingly, this is the system we selected.

vii. Fixture supports were located "on-grid" with a CSA and UL-approved feed system selected to cut installation costs. The installed costs presented in the cost section of this document are based on indirect luminaires with mounting locations on 12-foot centers that are "on-grid." Care must be exercised in this area. There are indirect luminaires that do not have this style of mounting and may cost as much as $300.00 more per classroom to install. A more complete discussion of this point can be found on the Finelite web site, www.finelite.com, under the section entitled *Guide to Contractors*.

- Teacher Control Center (TCC) to allow the teacher to select general or A/V mode and control the occupancy sensor during tests or quiet periods.

  i. The TCC needs to be located at the front teaching wall. The research indicated that when the controls were located next to the classroom door, the teacher would not disrupt the class by walking to the controls and then walking back to the main teaching area. In fact, we did not see the levels change in the control classrooms during the entire teaching year despite the existence of several rooms with four or more switches by the door.
  ii. The TCC faceplate needs to have clear, easy-to-understand labels. Since substitute teachers need to become comfortable with the classroom in a few minutes, the control panel needs to be very simple to understand. Accordingly, clearly labeled faceplates were selected over switching systems that used multiple push buttons to control scenes.
  iii. The TCC should use low-voltage, plug-and-play interconnections. A number of control protocols, including DALI, were examined for use in the classroom. The selection of a low-voltage, plug-and-play system was based on the following findings:
    1. Many control systems had dramatically more features than were needed to let the teacher control all the pertinent features in the classroom. Because these extra features cost more to purchase and to program, the complex systems were not deemed cost-effective for a classroom.
    2. We selected the 0- to 10-volt dimming system for systems with optional A/V or daylight dimming because this was a standard protocol with ballasts and controls provided by multiple vendors.
    3. A low-voltage system has lower installed costs than a system that runs in conduit and is easier to modify if any changes are needed.

- A Power Control Center located above the ceiling tiles that contains:
  i. Control Pack that switches power based on occupancy and is tied into the TCC by means of low-voltage, plug-and-play cables. The Control Pack also includes a 24-volt supply to power the system and sensors. To assist in troubleshooting, the Control Pack should contain indicators that show that the main 24-volt power supply is operating and that the occupancy sensor is generating a proper signal.

ii. Row Pack with relays that control whether the luminaire is in General or A/V mode. The Row Pack has a second 24-volt power supply to provide backup in case of a failure to the primary supply and is connected via low-voltage plug-and-play cables.
iii. Extension Pack with relays to control the General and A/V mode of the second row of luminaires.
iv. A contractor-supplied J-box that is used to make the splices to the main power supply, the power to the master classroom switch(s), and the feeds to the 2-rows of luminaires.

- Occupancy Sensor with "Quiet Time" operating mode
  i. The sensor should use dual technology, passive infrared and ultrasonic, to detect occupancy. Several manufactures make this style sensor.
  ii. The sensor should be positioned in the center of the ceiling. We originally mounted the sensors in one of the corners of the room. However, teachers put up easels that obstructed its view and the diagonal distance from the corner to the door in a 30 x 32-foot classroom was at the end of the sensor range. Teachers complained that they had to walk too far into a dark classroom to activate the sensor. Placing the sensor in the center of the classroom addressed these issues.
  iii. It was less expensive to install a plug-and-play sensor in the ceiling than several feet down the wall. Given the savings and increased performance, the decision was reached that sensor placement should be in the center of a 30 x 32-foot classroom.
  iv. Coverage is up to 30 x 32 feet per sensor. Above that, add a second sensor. Some options are outlined later in this section.
  v. Sensor setting from the factory should be:
     1. Time delay equal to 10 minutes
     2. Turn on with both signals (ultrasound and passive infrared)
     3. Keep on with one signal (ultrasound or passive infrared)

- Plug-and-play interconnections
  i. A low-voltage plug-and-play system is necessary to lower installed costs.
  ii. A common form factor should be selected. RJ 45 jacks are preferred due to their ready availability, if anything happens during installation of the factory-supplied and tested cables.
  iii. Plug-and-play cables shall be Plenum rated and UL listed.

- A single manufacturer that provides layout assistance, pricing, training, commissioning, and warranty support is important.
  i. Manufacturer should be able to guarantee system pricing to ensure proper budgeting and life cycle costs.
  ii. The ballast manufacturer will pass through a 5-year warranty on ballasts and a2-year lamp warranty.
  iii. The sensor and controls will pass through a 5-year warranty on all sensors and controls.

iv. The system manufacturer will warranty all other parts and the plug-and-play interconnections for 5 years. This manufacturer will also serve as the main center for a one-call support with respect to all system support issues.
v. A Use and Care Manual for the teacher and school facilities department should be provided for each classroom.

Options for the ICLS to deal with different classroom layouts, different levels of daylight in the room, and different use of A/V (current and anticipated) should include:

- Second occupancy sensor with plug-and-play cable should be available.

- Whiteboard luminaire with labeled faceplate and switches.

- A/V dimming. The only lamp that is dimmed is the T8 lamp in the downlight compartment. The two T8 lamps that provide the lighting for the General mode are on standard 1.18 BF instant-start ballasts. Following is an explanation as to why this unique approach was selected. During General mode, the teacher wants maximum light on the walls and the students' desks. (This is especially true when the maximum connected lighting load is less than 1 W/sq. ft..) In the A/V mode, the teacher may want to control light levels to direct students' attention for specific time periods. We found teachers used this capability not only with sophisticated A/V systems but also with basic-level overhead projectors. For example, we observed a teacher using an overhead projector to display an algebra problem to the class. As the teacher did this, she dimmed the T8 lamp to the lowest level. As a result, the screen (with the problem on it) was the brightest object in the room and commanded the attention of the students. After the teacher made sure the students understood the problem, she used a slide dimmer to increase the light to the maximum A/V level (about 35 fc on the students' desks.) The paper on students' desks became well lighted. This helped the students focus on solving the problem individually. At the same time, there was sufficient ambient lighting for the students to interact with the teacher. We watched the teacher repeat this exercise three times. Each time, the teacher focused the students on the problem and then re-directed them to individual problem solving. When the session was complete, the teacher returned to General mode and asked the students to put away the math books. In this way, the teacher used simple but effective ICLS controls to direct the students where to focus and for how long. We also observed simpler examples, where teachers used the dimming control to "quiet" the students after breaks or for group reading time in the lower grades. The final benefit of the A/V dimming mode that was selected is that it has about one-half the cost adder of a traditional full dimming system and actually provides a lower "low" level because there is only one lamp on the dimming ballast.

- Faceplates and switches for row control (2-row and 3-row with labeled faceplate should be available as well as having switches work with rooms with multiple entrances and switch locations.)

- Closed-loop continuous dimming for daylight and A/V control. The system should be capable of accepting a plug-and-play sensor that will control dimming ballasts on a closed-loop basis. While it is difficult, using currently available technology, to show a fast payback for dimming systems that control the light level in the classroom based on the level of daylight, schools may want to add this feature for reasons other than simply payback on energy savings. Accordingly, the ICLS should be able to support a full dimming system that allows the teacher to dim the light manually from the front of the classroom. At the same time, a closed-loop daylight sensor should be set to the maximum amount of electric light based on available daylight. The two controls work together with the lower of the two settings driving the light and the highest setting never exceeding the level indicated by the daylight sensor.

- Open-loop daylight control featuring stepped switching of T8 lamps. While switching lamps on or off based on the amount of daylight in the space creates more disruption to the teaching rhythm in the classroom than a closed-loop dimming system, it is much more affordable and generally easier to commission. The ICLS should be designed so that a school can add switching on or off entire rows, or lamps within a row, based on a sensor. Selection of a closed-loop system, open-loop system, or a manual system to control rows based on daylight in the classroom depends on factors, which include the nature of the daylight in the classroom, the cost of energy to the school, and the amount of daylight at the school's locations. A complete discussion of these factors is outside the scope of this study. The SCE Classroom Lighting Guideline has an excellent introduction to the issues in this area. The link is: www.sce.com.

- Additional rows of indirect luminaires with a new 96% reflective optical system that allows "general" and "A/V" mode operation, 3150 lumen T8 lamps, and 1.2 BF instant-start electronic ballasts (including luminaires and appropriate controls.) The system must be capable of working with three or more rows of luminaires to allow for different shaped classrooms or labs.

- Different ballast factors to keep power loads at approximately 1 W/sq.ft. for different classroom sizes.

Additional descriptions of ICLS components can be found in Appendix A that presents a performance specification that is generic (non-manufacturer specific), and in Manufacturer Literature (Appendix F) that contains information on one commercially available ICLS system.

DERIVATIVE ICLS PROJECT

Introduction

The initial scope of PIER Project 4.5 was expanded to study four additional questions. Finelite, The Watt Stopper, and AEC staff conducted a derivative study to address these issues. Southern California Edison (SCE) staff and their consultants played a central role by providing a well daylit training room to study different lighting plans and by developing the alternate plans to study. Los Angeles Unified School District (LAUSD) also played a key role in this phase of the study by providing input from a client's perspective. The four questions addressed were:

1. What was the impact of adding a dedicated, energy-efficient, and affordable whiteboard luminaire to the electric lighting plan? Particularly, the researchers wanted to see if increased vertical illuminations levels on the whiteboard (40 to 50 fc) would allow reduced illumination levels at the desk level (20 to 30 fc).

2. How would teachers react to a closed-loop dimming system that would continuously adjust the electric light based on the amount of daylight compared to an open loop system that switched lamps completely on or off based on daylight levels? And, could the researchers project a payback based on energy savings on the part of the system that controlled the electric light levels based on the daylight in the space?

3. What would be user response to providing the A/V mode of lighting by switching off lamps in the indirect luminaire that were closest to the white board or by dimming the lamps in the indirect luminaire? These layouts are shown in Appendix H as Examples 1 through 3 and were developed by SCE. The examples are also presented in their entirety in the SCE Classroom Lighting Guideline at www.sce.com.

4. What would be the life-cycle cost of these systems compared to the PIER ICLS developed in Project 4.5?

Approach

SCE provided a well daylit training room at their CTAC facility in Irwindale, California, to serve as a test laboratory for the different lighting layouts. The room was approximately 35 x 30 feet with an 11-foot 4-inch ceiling.

The room had been specifically built to demonstrate good daylighting practices. It had one wall with both view windows and top lighting windows. These had exterior light shelves to control direct sun light. Three skylights provided vertical illumination on the interior wall and the desks near the wall. The room had a 16-foot white board and a pull down A/V screen that would cover the whiteboard when lowered. The room was used for many different functions and used a desk system that was easy to reconfigure. Figure 5 provides the CTAC daylit classroom floor plan.

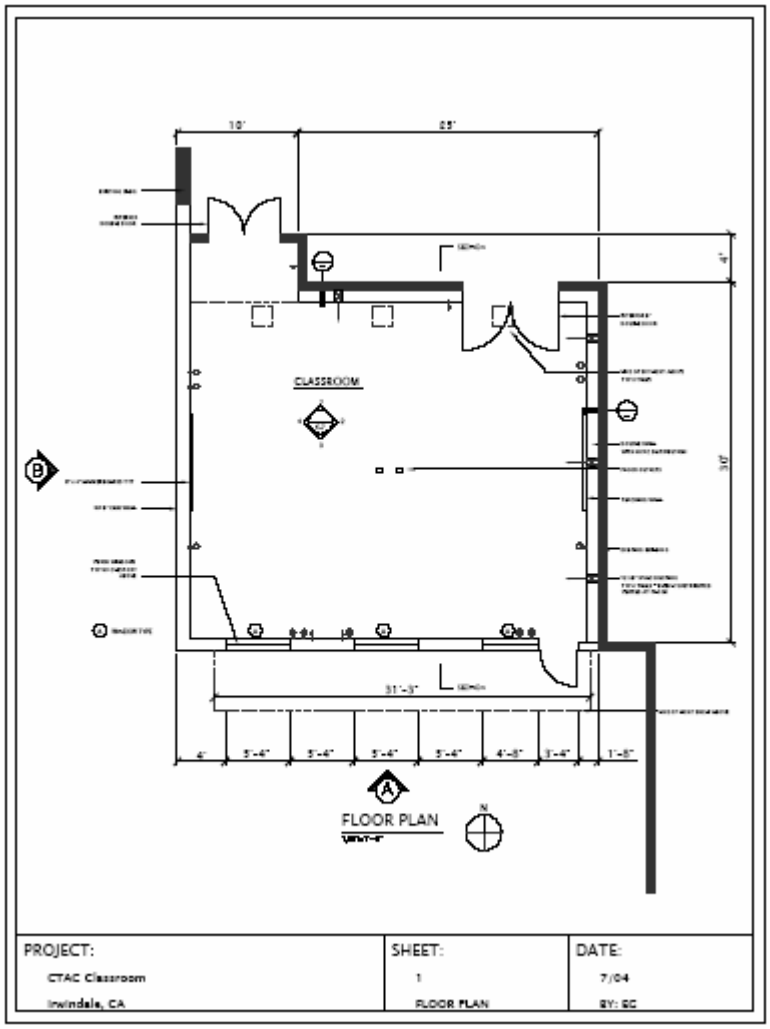


Figure 5: Floor plan of CTAC daylit classroom.

A newly developed, dedicated whiteboard luminaire was installed to light a 16-foot long whiteboard that was on a wall at right angles to the wall with the daylight and view windows. The 12-foot luminaire was mounted to the ceiling and approximately 3-feet back from the wall that contained the whiteboard. Controls for the whiteboard were at the front of the classroom.

A special purpose indirect luminaire and control system was built and installed in the training room. The indirect luminaire was built so it would operate as if it was a 2-T8 lamp driven by 1.2 BF electronic ballasts luminaire providing approximately 90% uplight and 10% downlight. The luminaire would also operate as a 1-T5HO indirect luminaire with the lamp on a dimming system. Switches in the control panel, mounted on a side-wall (see Figure 6), determined the mode of luminaire operation. The panel also contained additional switches that controlled which T8 lamps would be turned off based on the amount of daylight in the space. This let the researchers simulate the effect of turning an entire row off at one time or only one row of lamps at a time based on daylight.

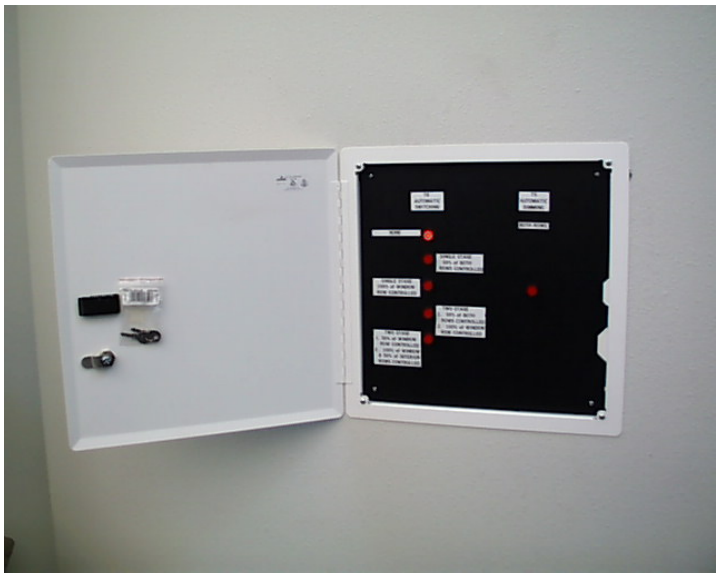


Figure 6: Control panel at CTAC classroom that provided switching from T-8 step switching lighting system to T-5HO automated dimming system.

Two separate Teacher Control Centers were provided. One Teacher Control Center was located to the left hand side of the whiteboard and controlled the system when the luminaire was in 2-T8-mode. The second Teacher Control Center was to the right of the whiteboard and controlled the system when the luminaire was in the 1-T5HO-mode.

A state-of-the-art light level sensor with a new commissioning system was installed to control the closed loop dimming system. This was the sensor that was developed in PIER LRP Project 3.3. The open loop control sensor was The Watt Stopper LS100. The commissioning of the sensor was performed by The Watt Stopper personnel and observed by researchers from the AEC, Finelite, and SCE staff.

Researchers took numerous light level readings under various daylight and electric light conditions. They converted these readings into graphical representations that are part of Appendix G. Researchers also conducted a number of discussions with presenters that used the room and were present during extended meeting and presentations in the room (Reference Figure 7).

The LAUSD provided useful input regarding all aspects of the derivative project. As a result, the school district is preparing their own lighting and lighting control specification based on some of the ICLS findings.

Figure 7: Pictures of lighting scenarios at the CTAC classroom. Starting at the top left is daylight only; Top right is T-5HO lighting system; Bottom left is T-8 lighting in A/V mode; Bottom right is T-8 lighting with whiteboard lighting on.

Findings

Researchers documented the following key findings.

- The addition of a dedicated whiteboard luminaire to the classroom layout had a positive impact. The results were:
    a. The luminaire installed was a 12-foot long whiteboard luminaire with 1 T8 lamp in cross section and 0.88 BF electronic ballasts. It was mounted 11 feet 4 inches above finished floor and 36 inches from the wall that contained a 16-foot long whiteboard.
    b. With no daylight or other electric lights on, the illuminance on the whiteboard ranged from 15 fc in the lower corner to 33 fc in the top center (2.2 to 1 uniformity).
    c. When the electric lights were turned on, the combined levels were:
        i. With the whiteboard luminaire and the 2-T8 with 1.2 BF system turned on, the illumination on the whiteboard was 42 fc in the corner, 62 fc at the top (1.5 to 1 uniformity).

ii. With the whiteboard luminaire and the 1-T5HO system turned on, the illumination on the whiteboard was 34 fc in the corner, 53 fc at the top (1.6 to 1 uniformity).
iii. Additional illumination could have been provided if the whiteboard luminaire was made longer. However, the researchers wanted to test the SCE layout that used 12-foot luminaires. If the luminaires were mounted as outlined in the guideline, additional vertical illumination would have been achieved. The guideline recommends mounting the luminaire approximately 18-inches from a 10-foot ceiling.
iv. The whiteboard luminaire was left as originally installed based on feedback that it provided excellent illumination as installed and moving it lower would have meant substantial changes both to the A/V projector and screen in the room.

d. The CTAC daylit classroom is one of the most requested rooms in this heavily used facility. The response of presenters and attendees in the room to the whiteboard luminaire was uniformly positive. The positive comments were made in both the T8 and T5HO modes. It is interesting to note that the T5HO light level of 33 fc on the desks is lower than generally found in classrooms or training rooms. The positive response to the room in this condition supports the idea that a well-lighted white board actually does let the illumination at desk-level decrease without creating dissatisfaction. However, due to the nature of the presentations made in this training room, we were not able to conduct the type of in-depth teacher surveys that were done for the base project. Nevertheless, attendees including architects, lighting specifiers, engineers, school personnel, and trainers have all complimented SCE on the room and its lighting.
e. Additional findings included:
i. The wall with the white board became the brightest surface in the room and helped focus attention of the students on the main teaching wall. Since reading cramped handwriting or low contrast material on chalkboards is often the most difficult task in a classroom or training room, the illuminance on this wall increased contrast and made this task easier as well.
ii. The switch for the whiteboard luminaire should be at the front of the classroom. The teacher will want to turn the luminaire off when going to the A/V mode. Properly locating the switch was important to the user satisfaction levels.
iii. While the whiteboard luminaire could have been automatically switched on or off when the presenter selected the A/V mode (whiteboard luminaire off) or General mode (whiteboard luminaire on), presenters appreciated having even more control. For example, when the whiteboard luminaire is switched on and the room lights are in A/V mode or dimmed, an interesting dynamic occurs; As a person enters the classroom, the material on the board is quite bright; however, the general light levels are sufficiently low to create a quiet or calming effect. This might be useful when the instructor wants the students to enter the classroom; open a textbook; and start an assignment right away.

iv. The installed cost of this 12-foot luminaire was estimated at $0.47 per square foot ($447.00.) This includes luminaire, lamp costs, and installation labor plus traditional contractor mark-ups. It does not include sales tax. However, the incremental cost may be somewhat less. This is due to the fact that the whiteboard was lighted so uniformly that it may be possible to reduce the row length to 20-feet from 24-feet. On the other hand, at least one client, has found that a combination of the dedicated whiteboard luminaire and two 24-foot runs with standard 0.88 BF ballasts provides exactly the light levels they need at less than 0.8 W/sq. ft.. Since new school construction costs often run $120 to $175 per square foot, the dedicated whiteboard luminaire brings such benefits for so little cost that many architects and specifiers may want to add it to their designs.

- User response to closed loop dimming system was positive. The response to the stepped T8 switching was more difficult to gauge. Here are the findings:
    a. The slide dimmer switch was located at the front of the classroom and easy to use. The sensor that provided the maximum level of electric light based on the daylight in the room worked well. Even when the sensor was “limiting” the maximum electric light level due to the daylight in the space, the teacher could still dim the system to lower levels. The sensor selected was the state-of-the art Watt Stopper Model 301. The photo sensor is commissioned via a hand-held remote unit. One will be needed for each school or site. Extensive information on this sensor can be found by reviewing PIER LRP Project 3.3. The unit should become commercially available during 2006. Final pricing has not been set at the time of the report. The costs in the Life Cycle analysis section of this document are based on best estimates.
    b. The researchers found that commissioning went smoothly and the unit has the advantage of creating the documentation that the 2005 Title 24 code requires to indicate that the system was properly installed and set up. Since commission issues are often one of the biggest obstacles to overcome in closed-loop systems, the benefits provide by this new generation sensor should help architects and specifiers achieve their project goals for integrating daylight and electric light.
    c. Because the nature and amount of daylight varies so much from classroom design to classroom design, it was impossible to come up with a definitive payback review for the closed-loop system based on potential energy savings. Prior work indicates that savings of up to 50% have been achieved. However, when the base-level energy load is approaching 0.8 W/sq.ft.. A 50% savings may only equate to savings of $0.40 per day per classroom. As indicated earlier, the benefits of closed-loop dimming extend beyond energy-related payback and the incremental cost of this system needs to be viewed based on overall design objectives.
    d. The stepped daylight switching system did not operate as expected when the luminaire was in T8 mode. The primary reason was that the level of daylight in the space was below expected levels. The SCE-developed lighting guidelines for a typical school classroom showed between 120 and 200 fc of desk-level illumination near the windows. The SCE training room, however, was so well designed with light shelves and other features that it had a maximum of only 50 to

60 fc of daylight illumination near the windows. Accordingly, the sensor never experienced the condition where the T8 lamps should be switched off. This led to several observations:

i. We were unable to get first hand feedback from the presenters about the disruption they felt when an entire row of lamps automatically shut off at one time. Further, since presenters are not in the classroom every day like teachers are, the researchers were unable to assess how distracting this would be after the teacher became familiar with it happening each day.
ii. The experience indicated that a closed-loop dimming system can be installed in rooms with much wider ranges of daylight levels and perform satisfactorily with high user acceptability. While there is a cost adder associated with closed loop dimming as compared to row switching, the cost of carefully designing a stepped switching system and the unknown factor of user acceptability may offset the apparent initial price difference.
iii. After the researchers found that the automatic stepped switching system did not perform as expected, the system was modified to let the lamps be controlled manually. This let the researchers determine the light levels under various stepped switching alternatives. These measurements indicate very satisfactory levels are achieved with stepped switching. Accordingly, the real issues surrounding stepped switching remains whether or not the luminaire can automatically switch without creating objectionable disruption and still deliver cost-effective energy savings based on daylight.

- The findings of PIER 4.5 recommend that the classroom should have dedicated A/V mode. This extended study explored two additional ways to provide A/V lighting. The original study used a separate compartment with a dedicated lamp to provide downlight that did not create veiling reflections on the screen. (For classrooms with extensive A/V use, the downlight was dimmed for extra teacher control.) However, A/V mode can also be provided by lamps on a continuous dimming system or by switching off the uplights near the screen that create the most glare. The special luminaire let the instructors compare and contrast the A/V mode under the 1-T5HO dimming system and the 2-T8 indirect mode where lamps were switched off. The figures in Appendix G indicate the light levels that were obtained in each of these configurations. Computer simulations are also included that indicate light levels at specific locations in a typical 30 x 32-foot classroom with 10-foot ceilings. In addition to this data, researchers had the following observations:
    a. Daylight illumination in the test classroom varied from 5 fc at 8:00 AM to 40 fc at 2:00 PM and back down to 25 fc at 4:00 PM. These levels are shown on the figures in Appendix G. While the teacher had access to manual blinds that could reduce the amount of daylight, they did not generally use them. Therefore, during the A/V mode, there was always daylight in the room.
    b. Based on the daylight present, the researchers found that during both alternate A/V modes (T8 switching and T5HO dimming) there was sufficient light to take notes and see the teacher’s face. Furthermore, both modes significantly reduced the vertical illuminance levels on the screen.

c. The computer simulations indicate that in the 2-T8 switched mode the light on the front screen drops to 4 fc. The desk-level illuminance from the electric light provides a low of 4 fc on the desks in the front row and 28 to 40 fc on the desks in the back row. When daylight levels of 20 to 40 fc are added to the electric light level, the combined lighting would be 24 to 44 at 4:00 PM or 44 to 80 at noon. In either case, the uniformity is excellent (better than 2 to 1.) Accordingly, if the classroom is well daylighted, then the switched mode to provide A/V mode should work well. (However, blinds are needed for most classrooms since some daylight levels of 120 to 200 fc near the windows will negatively impact projections on the screen.)
d. Similar to the findings above, the system with 1-T5HO lamps on a full dimming system provided excellent A/V lighting in the classroom. In a fully dimmed mode, the T5HO lights provide less than 1fc on the desks and less than 1fc vertical illuminance on the whiteboard. The slide dimmer made it easy to balance the light on the whiteboard with light on the desk. (As above, manually controlled blinds should be provided to ensure the daylight could be reduced to avoid veiling reflections during A/V presentations.)

Life cycle cost comparison

The following section compares the life cycle costs for three specific examples. Project 4.5 gratefully acknowledges the contribution of the examples by SCE with support from Clanton and Associates. More information about the examples can be found in Appendix H.

- In Example 1, the ambient lighting system uses 2 rows of 20’ semi-indirect luminaires that are suspended in 2 rows of 5 each. Each luminaire employs (2) high lumen T8 lamps, all powered from high ballast factor electronic ballasts. The whiteboard task light is a linear wallwasher about 12 feet long that uses (3) Super T8 lamps.
- Example 2 uses a (3) lamp Super T8 luminaire. The two outer lamps are used for a semi-indirect ambient lighting scene, and the third inner lamp is separately switched for use as a task light during projection and A/V presentation. In this design, 2-20’ PIER luminaires are suspended in 2 rows of 5 each.
- In Example 3, the ambient lighting system uses 2 rows of 20’ direct-indirect luminaires are suspended in 2 rows of 5 each. Each luminaire employs (1) high lumen T5HO lamp, powered from high ballast factor electronic dimming ballast. The whiteboard task light is a linear wallwasher about 12 feet long that uses (3) Super T8 lamps.

Please note that all costs are estimated prices that are negotiated between a school district and their suppliers and contractors. Several conclusions can be reached:

1. The base PIER system remains the lowest initial cost system. However, the projected energy savings from the stepped daylight switched system create sufficient energy savings that the life cycle costs of the base PIER system and the SCE Example 1 become the same over a 20-year period. The closed loop dimming system remains the most expensive. However, the incremental cost, on a life cycle-basis, for the complete dimming system is under $0.75 per square foot.

2. The initial incremental cost of adding the whiteboard luminaire is partially offset by cutting the length of the rows from 24-feet to 20-feet. In fact, in the SCE Example 1, the material cost is nearly the same as for the 2-24 run system with the dedicated chamber for the A/V lamp. This means the incremental initial cost is the labor to install the whiteboard luminaire.
3. The full dimming system with closed loop dimming provides the greatest level of control and user satisfaction. However, it also has the highest initial and lifecycle cost. Decision makers will need to determine whether or not these added benefits are consistent with the overall school design goals and budgets.
4. All costs are estimates based on the luminaires, sensors, controls, and plug-and-play interconnections used in the test classrooms. The cost of indirect luminaires and integrated controls can vary widely from one manufacturer to another. When specifiers are developing project budgets, they must exercise care to be specific about the performance they want and the sensors and controls that are selected. The performance specification presented in Appendix A is designed to help do this. They also must work with the client and their project managers to make sure the proper items are quoted. Otherwise, costs may be greater than expected and the benefits not achieved.

The cost information for the three examples is shown in Table 5 and categorized by component with material and labor costs. The information enables school representatives, lighting specifiers, and contractors to measure the cost against the benefit of the various system designs and components.

Component	**SCE Example 1**	**SCE Example 3**	**PIER 4.5 System**
First Costs:			
Indirect Suspended Luminaire			
Luminaire Type	S10- 2T8-EP-DC-CP	S10-1T5HO-Dimming-EP-PLV	S10-3T8-EP-DC-CCO-PLV
Luminaire row length	20.00	20.00	24.00
ballast type	T8 1.2 BF IS	T5HO dimming	T8 1.2 BF IS
# luminaire rows per classroom	2.00	2.00	2.00
lamp type	T8	T5HO	T8
# lamps in cross section	2	1	3
# lamps per row	10	5	18
Price per lamp	2.75	9.00	2.75
Whiteboard Luminaire			
Luminaire type	12-foot SX2-1T8	12-foot SX2-1T8	none
Luminaire length	12.00	12.00	n.a.
ballast type	T8 .88 BF	T8 .88 BF	
# luminaire rows per classroom	1.00	1.00	
lamp type	T8	T8	
# lamps in cross section	1	1	
# lamps per row	3	3	
Price per lamp	2.75	2.75	

Component	SCE Example 1	SCE Example 3	PIER 4.5 System
Total luminaire material costs	$1,867.75	$2,592.45	$1,866.88
Total luminaire installation costs at $75.00 / hour	$329.00	$329.00	$293.00
Control and Sensor Costs			
includes:			
Switches			
Teacher Control Center, and Control Packs			
Plug-and-play interconnections			
Occupancy Sensor			
Daylight Control			
Total sensor and control materials	$658.00	$848.00	$508.00
Total sensor and control labor	$590.00	$540.00	$390.00
Total System Cost			
(Material)	$2,525.75	$3,440.45	$2,374.88
(Labor)	$919.00	$869.00	$683.00
Contractor OH&P (15% material cost)	$378.86	$516.07	$356.23
Contractor Supervision (10% labor)	$91.90	$86.90	$68.30
General Conditions (7.5% material and labor)	$258.36	$323.21	$229.34
Total System Cost First Cost	**$4,173.87**	**$5,235.63**	**$3,711.75**
First cost per square foot	**$4.35**	**$5.45**	**$3.87**
Expected power density (watts per square foot)	*0.60*	*0.50*	*0.80*
Annual Costs:			
Lamp rated hours (derated to reflect IS ballast cycles)	15000.00	20000.00	20000.00
Annual hours of general operation (burning General lamps)	1750.00	1750.00	1500.00
Estimated years to replace general lamps	8.00	11.00	13.00
Annual hours of A/V mode operation (burning A/V lamps)			250.00
Estimated years to replace A/V lamps			13.00
Estimated annualized re-lamping costs	$4.69	$5.00	$4.58
Annual energy for General ($.13 / kwhr)	$131.04	$109.20	$149.76

Component	SCE Example 1	SCE Example 3	PIER 4.5 System
Annual energy for A/V mode ($.13 / kwr)			$12.48
Total Annual Energy Cost	$131.04	$109.20	$162.24
Estimated annualized cleaning cost	$13.75	$13.75	$13.75
Estimated annualized heavy maintenance	$13.75	$13.75	$13.75
Total Annual Costs	**$163.23**	**$141.70**	**$194.32**
Life Cycle Cost:			
First Cost	$4,173.87	$5,235.63	$3,711.75
Annual Cost	$163.23	$141.70	$194.32
Years of operation	20.00	20.00	20.00
Inflation rate for Annual Costs	0.04	0.04	0.04
Salvage value at end (20% of first cost)	-$834.77	-$1,047.13	-$742.35
Rebates and incentives:	0.00	0.00	0.00
Present Value of All Costs	**$5,794.09**	**$6,444.10**	**$5,795.01**
Present Value of All Costs per square foot	**$6.04**	**$6.71**	**$6.04**

Table 5: Cost information categorized by component with material and labor costs for three different classroom lighting systems evaluated under the derivative ICLS project.

CONCLUSIONS

With input from representatives of the Collaborative for High Performance Schools (CHPS), Finelite Inc. used a combination of best practices and new technologies to develop and test an integrated classroom lighting system (ICLS) for K-12 classrooms. The basic system includes indirect luminaires with energy efficient T-8 lamps and electronic ballast, 96% reflective material within the fixture, a teacher control center located at the front of the classroom, and plug-and-play components.

Working with six California schools, variations of the ICLS were installed in 19 classrooms. Researchers continuously monitored the ICLS and other baseline classrooms for one school year and analyzed the resulting data. The data shows a 30 to 50 percent reduction in energy use in the ICLS classrooms with improved lighting on the teaching walls and better flexibility for adjusting light levels during audio/visual presentations. The ICLS also provides approximately 40 to 70 footcandles of light on student's desks while maintaining less then 1 W/sq.ft. (0.9/ W/sq.ft.) in the classrooms. 2005 Title-24 codes require schools to have 1.2 W/sq.ft. or less in new classrooms. Teachers were also surveyed and provided positive responses to the light levels and the quality of light in the classrooms. A derivative project that involved installing a hybrid ICLS in a daylit training classroom was also completed.

Based on the results of Project 4.5, the benefits of an Integrated Classroom Lighting System are well tested and documented. School districts and their architects and lighting designers should consider the following criteria for classrooms:

- Use indirect luminaires to provide general classroom illumination. Light a 30 x 32-foot classroom with 2 rows of a high-performance, indirect suspended luminaire with 3100 lumen T8 lamps and 1.2 BF T8 electronic ballasts. Use different T8 ballast factors for different size classrooms or for classrooms with extensive daylight.

- Provide an A/V-appropriate lighting mode in classrooms. During A/V mode, reduce light on the front teaching wall while keeping an appropriate level of light on the students' desks for note-taking and class interaction.

- Give the teacher control at the front of the classroom to change between General and A/V modes of operation and to control other functions and options.

- Provide ways to control the electric light to reflect the amount of daylight in the classroom. Depending upon the nature of the daylight in the classroom, use manual control, stepped switching, or automatic dimming based on daylight levels.

- Allow the teacher to keep the lights on during periods of quiet time for tests or periods of individual study or work. Position the occupancy sensors in the ceiling to minimize obstruction by objects in the room.

- Select a system with plug-and-play sensors and controls and that have a single manufacturer as the point of support for applications, pricing, and field support.

- Provide modularity and options to deal with different classroom layouts, teaching and A/V requirements, and daylighting conditions.

The ICLS provides quality lighting and is an economical alternative to typical classroom lighting designs and, to help minimize support and warranty costs, is bundled as a package system with one source of responsibility. Policy makers may want to use these findings to set overall guidelines that encourage ICLS use. In this way, they can help ensure that energy savings together with a better teaching environment are implemented in as timely a manner as possible in the State of California.

APPENDIX A: CLASSROOM LIGHTING PERFORMANCE SPECIFICATION

APPENDIX B: ENERGY METHODOLOGY

APPENDIX C: TEST DATA FOR ALL CLASSROOMS

APPENDIX D: TEACHERS SURVEY REPORT

APPENDIX E: CLASSROOM LIGHTING TEMPLATES

APPENDIX F: MANUFACTURER LITERATURE

APPENDIX G: SCE DAYLIT CLASSROOM ILLUMINANCES

APPENDIX H: SCE CLASSROOM LIGHTING EXAMPLES