Daylight Dividends

CAPTURING THE DAYLIGHT DIVIDEND

FINAL REPORT

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Abstract

Capturing the Daylight Dividend conducted activities to build market demand for daylight as a means of improving indoor environmental quality, overcoming technological barriers to effective daylighting, and informing and assisting state and regional market transformation and resource acquisition program implementation efforts. The program clarified the benefits of daylight by examining whole building systems' energy interactions between windows, lighting, heating, and air conditioning in daylit buildings, and daylighting's effect on the human circadian system and productivity. The project undertook work to advance photosensors, dimming systems, and ballasts, and provided technical training in specifying and operating daylighting controls in buildings. Future daylighting work is recommended in metric development, technology development, testing, training, education, and outreach.

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Rensselaer Polytechnic Institute's Lighting Research Center (LRC)

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Seed Research Recipients

Professor G. Z. Brown, University of Oregon, Mechanical Shade Control and daylighting design tools
Professor Kevin Van Den Wymelenberg, University of Idaho, how to develop a regional daylighting lab
Dr. Ihab Elzeyardi, University of Oregon, Biophilia effect of daylighting

Dr. Martin Moeck, Pennsylvania State University, The effects of different top lighting and side lighting strategies
Dr. Jong Jin-Kim, University of Michigan, The value of windows
Dr. Herbert Eckerlin, North Carolina State University, Identifying and correcting the barriers to daylighting in schools
Mr. Michael Nicklas, Innovative Design, A guide to daylighting schools

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Executive Summary

Capturing the Daylight Dividend is a joint program of the U. S. Department of Energy (US DOE), New York State Energy Research and Development Authority (NYSERDA), California Energy Commission (CEC), Connecticut Light and Power Company (CL&P), Iowa Energy Center (IEC), North Carolina Daylighting Consortium (NCDC), Northwest Energy Efficiency Alliance (NEEA) and the Lighting Research Center (LRC). The project is further supported through a sharing of information with the Energy Center of Wisconsin (ECW).

There are three project objectives:

- Building market demand for daylight as a means of improving indoor environmental quality
- Overcoming technological barriers to effectively reap the energy savings of daylight
- Informing and assisting state and regional market transformation and resource acquisition program implementation efforts

To achieve these goals, two major areas of research where intensive work needs to occur if effective daylighting is to become a common feature in all non-residential buildings have been identified.

- Clarifying the benefits of daylight (Why is daylight important?)
- Advancing the technological components – photosensors, dimming systems, ballasts

The Steering Committee, made up of representation of all funding sponsors, guided the program throughout its three year history. The Steering Committee met twice annually to set a research agenda, approve budgets, review program progress and share information regarding their individual efforts in promoting effective daylighting. The guidance provided by this group assured the success of the program.

Identifying the barriers to the widespread use of daylight in non-residential buildings was the cornerstone for the Capturing the Daylight Dividends program. All other work is predicated on the barriers and research identified as being required to gain widespread use.

To identify the barriers and research requirements, the program undertook two studies. Five focus groups were conducted across the country with building designers, developers and owners to determine the barriers to the use of daylighting from both a design and ownership perspective. The primary barriers identified were:

- The capital cost required to use daylighting and the long payback (high up front costs)
- Problems with technology (e.g., daylighting requires a lot of technology)
- The building’s site location and access to sunlight
- The added design/financial risks
- Inconsistency in lighting across the building and during the course of the day

Nearly 200 current and on-going research studies were reviewed to make recommendations where new research was needed to fill knowledge gaps. “The Benefits of Daylight through Windows” report was peer reviewed prior to publishing the results. The reports conclusions lead to four topics that deserve additional research. They are:

- Reduce the likelihood of discomfort from windows, so as to minimize behaviors that limit the admission of daylight

- Quantify the financial return on windows in terms of what people are prepared to pay for them, regardless of the reasons why
- Explore the impact of daylight operating through circadian system on task performance
- Test the biophilia hypothesis; i.e., that humans have an innate need to be in contact with nature. This is important because it is the main reason why windows are inherently superior to electric lighting

These two reports set the agenda for the research phase of the Capturing the Daylight Dividends program.

A review of program deliverables outlined by US DOE and the program's Steering Committee indicates that all tasks were met approximately on time and on budget. These deliverables include:

- market research into the barriers facing daylighting
- determining the current research work in daylighting and what research still needed to be completed
- technology development and testing
- building systems energy interactions between windows, lighting, heating and air conditioning in daylit buildings
- examination of daylighting's effect on the human circadian system and productivity
- nine seed research projects conducted by major universities throughout the United States
- three case studies
- two demonstrations of emerging daylighting technologies
- development and upkeep of a dedicated website
- educational programs for building designers, owners and managers
- outreach efforts to promote the use of effective daylighting

Details of all research efforts are presented within the appropriate task section that follows this summary.

A revenue and expense summary follows. Expenses exceeded revenues by approximately $24,000 or 1.4%

Revenue	
US DOE	$850,000
NYSEERDA	$348,954
CEC	$150,000
CL&P	$150,000
IEC	$75,000
NCDC	$15,000
NEEA	$150,000
TOTAL	$1,738,954

Budget and Expenditures by Task	Budget	Expenses
Task 1: Program Operations / Priority Setting	$455,154	$459,809
Task 2: Conduct RD&D Activities	$459,500	$476,262
Task 3: Seed Research	$320,300	$299,520
Task 4: National, State & Regional Daylighting Activities	$30,000	$17,000
Task 5: Demonstration Projects	$296,015	$217,338
Task 6: Dissemination, Education & Outreach	$177,985	$292,998
TOTAL	$1,738,954	$1,762,927

Capturing the Daylight Dividend program has made great strides to overcoming many of the barriers defined through market research conducted at the beginning of the program. However, there remains much work to do if effective daylighting is to be accepted into the mainstream of building design. It is recommended that the program's efforts continue and be focused on metric development, technology development and testing and training, education and outreach.

Task 1: Program Operations and Priority Setting

Task 1.1: Steering Committee

A Steering Committee was enacted to direct the activities of the Daylight Dividend program. Each funding sponsor was allowed to place one person on the Steering Committee. Steering Committee members, throughout the three years, included:

- Joel Chaddock, US Department of Energy
- Peter Douglas and Marsha Walton, New York State Energy Research & Development Authority
- Donald Aumann, Eric Stubee and Michael Seaman, California Energy Commission
- Samuel Fankhauser, Connecticut Light & Power Company
- John House and Curt Klaassen, Iowa Energy Center
- Russell Leslie, Lighting Research Center
- Dona Stankus, North Carolina Daylighting Consortium
- Amy Cortese and Joel Loveland, Northwest Energy Efficiency Alliance

Other interested parties or Steering Committee alternates include:

- James Brodrick, US Department of Energy
- Abby Vogen, Energy Center of Wisconsin
- Stephen Kalland, North Carolina Solar Center
- Edward Petrow, Lincoln Technical Services (project consultant for DOE)

Peter Morante of the LRC acted as program manager on behalf of the Daylight Dividends sponsors.

The Steering Committee set research priorities and program budgets and reviewed all completed work. The Lighting Research Center coordinated program activities under the direction of the Steering Committee through a sub-contract with NYSERDA, the prime contractor with US DOE. The LRC:

- Facilitated all program activities including preparing research and budget proposals, scheduling and conducting Steering Committee meetings and other assignments given it by the Steering Committee.
- Conducted research authorized by the Steering Committee when appropriate.
- Solicited seed research projects and awarded and coordinated contracts for these projects as directed by the Steering Committee.
- Reported on activities and results each month to all program sponsors and other interested parties.
- Prepared billing and invoicing.
- Suggested annual budget by task and sub-task.
- Maintained a website.
- Worked with sponsors and partners to seek additional funding as appropriate.
- Prepared Daylight Dividends publicity and disseminated information.

To accomplish the above tasks, the Steering Committee met twice annually to review and approve research activities and a budget. Notes of all meetings are included in Appendix A.

The approved program budgets and estimated expenditures by year and task are included in Appendix B.

Task 1.2: Peer Review of “Human” Benefits of Daylighting Research

To evaluate existing and on-going research into the “human” benefits of daylighting, the LRC, in 2003, undertook an extensive review of this body of work. The results have informed the Steering Committee of where new research was needed to fill knowledge gaps that will assist in the promotion of daylighting in buildings. This effort was led by Dr. Peter Boyce of the LRC with all work being reviewed by a distinguished panel of peers. These peers were chosen for their expertise in different aspects of human interaction with daylight and/or productivity. The peer review panel included:

- Dr. Kit Cuttle, University of Auckland
- Dr. Judy Heerwagen, J.H. Heerwagen and Associates
- Dr. Vivian Loftness, Carnegie-Mellon University
- Dr.Arnold Wilkins, University of Essex

Because of its length, only the executive summary of the report is presented here. The full report “The Benefits of Daylight through Windows” can be found at the program’s website, www.daylightdividends.org. The implications for additional research needs are included in the executive summary.

The Benefits of Daylight through Windows

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12th September, 2003

Executive Summary

The use of daylight as the primary light source in buildings is of interest to those concerned with energy conservation because it is assumed to minimize the use of electricity for lighting. However, it is difficult to justify the cost of extensive daylighting on the basis of energy savings alone. Rather, to justify the widespread use of daylight in buildings it is necessary to demonstrate that such use has a beneficial financial impact for the organization owning and/or occupying the building. This literature review considers the impact of daylight on human performance and workplace productivity; human health; and financial return on investment. These impacts of daylight are reviewed for buildings that are used for work and for which daylighting has been extensively studied, namely offices, schools, hospitals, and retail stores. Daylight in housing is not considered. This literature review examines the benefits and problems of both daylight, as light, and windows, as the most commonly used method to deliver daylight. From this literature review, a research agenda is developed.

The following conclusions are drawn from the literature review:

1. Physically, daylight is just another source of electromagnetic radiation in the visible range. Electric light sources can be constructed to closely match a spectrum of daylight, but none have been made that mimic the variation in light spectrum that occurs with daylight at different times, in different seasons, and under different weather conditions.

2. Physiologically, daylight is an effective stimulant to the human visual system and the human circadian system.

3. Psychologically, daylight and a view are much desired.

4. The performance of tasks limited by visibility is determined by the stimuli the task presents to the visual system and the operating state of that system. Daylight is not inherently better than electric light in determining either of these factors. However, daylight does have a greater probability of maximizing visual performance than most forms of electric lighting because it tends to be delivered in large amounts with a spectrum that ensures excellent color rendering.

5. There can be no guarantee that daylight will always be successful in maximizing visual performance. Daylight can cause visual discomfort through glare and distraction, and it can diminish the stimuli the task presents to the visual system by producing veiling reflections or by shadows. The effectiveness of daylight for visual performance will depend on how it is

delivered. The same conclusion applies to electric lighting

6. People will take action to reduce or eliminate daylight if it causes discomfort or increases task difficulty.

7. The performance of both visual and non-visual tasks will be affected by disruption of the human circadian system. A disrupted circadian system will also create long-term health problems. Exposure to bright light during the day and little or no light at night will accurately entrain the circadian system. Daylighting is an attractive way to deliver bright light during the day.

8. Different lighting conditions can change the mood of occupants of a building. However, there is no simple recipe for what lighting conditions produce the most positive mood. Windows are strongly favored in work places for the daylight they deliver and the view out they provide, as long as they do not cause visual or thermal discomfort or a loss of privacy. Whether windows will produce an improvement in mood seems to depend on what the individual's preferences and expectations are. For people who prefer daylight but who have become accustomed to little daylight, moving into a well daylighted space can be expected to lead to an improvement in mood that will diminish over time as new expectations are established. For people who prefer daylight and who are accustomed to a lot of daylight, moving into a space with little daylight is likely to lead to a deterioration in mood that will recover over time.

9. The understanding of how mood influences productivity is weak. Different studies have emphasized worker happiness, well-being, and job satisfaction as predictors of productivity while others have suggested that productivity is itself a generator of feelings of happiness, well-being, and job satisfaction. The basic problem for daylighting is that mood is subject to so many influences that unless the lighting is really uncomfortable, its influence is likely to be overshadowed by many other factors.

10. Exposure to daylight can have both positive and negative effects on health. The strongest effects occur outdoors. Exposure to daylight outdoors can cause tissue damage, which is bad, and generate vitamin D, which is good. Daylight and sunlight delivered through glass will have much less short wavelength ultra-violet (UV-B) radiation than the same radiation outdoors, but can still have adverse effects on people who are sensitive to ultra-violet radiation. Daylighting that makes what needs to be seen difficult to see can cause eyestrain. Conversely, daylighting that makes what needs to be seen easy to see can reduce eyestrain. Windows that provide a view out as well as daylight, can reduce stress and hence reduce the demand for health services. Daylight reduces the incidence of health problems caused by the rapid fluctuations in light output typical of electric lighting.

11. A wall containing windows costs more to construct and maintain than one without. These costs may be offset by reductions in building operating costs. However, the presence of windows is believed to have a positive effect on the rental value of a space.

12. Daylighting of a conventionally windowless retail space can have a positive effect on sales.

From these conclusions, four topics that deserve research stand out. They are:

- Reducing the likelihood of discomfort from windows, so as to minimize behaviors that limit the admission of daylight
- Quantifying the financial return on windows in terms of what people are prepared to pay for them, regardless of the reasons why
- Exploring the impact of daylight operating through the human circadian system on task performance
- Testing the biophilia hypothesis; i.e., that humans have an innate need to be in contact with nature. This is important because it is the main reason why windows are inherently superior to electric lighting

There are many other topics that could be examined, but some, such as examining the effect of daylight on visual performance, seem unnecessary as knowledge in that area is already sufficient to predict the results. Others, such as examining the effect of daylighting on mood and hence productivity, could be undertaken but given the amount of work that has already been done in this area and the confusing pattern of results obtained, the probability of success is low.

In the program’s second year a review of newly published data regarding the human benefits of daylighting was conducted by the LRC (Dr. Peter Boyce) for the Daylight Dividends program. Reports conducted by the Heschong-Mahone Group for the California Energy Commission on the topic of productivity and interior environments were reviewed. These reports described epidemiological studies of the impact of daylight on: (1) the performance of office workers, (2) merchandise sales in a retail store chain and (3) the progress of elementary school children.

The review makes certain observations about the methodology applied and the effects of daylight.

- Attempts at replication are valuable. Effects that can be replicated can be relied on. Effects that cannot be replicated cannot be relied on.

- Variables in multiple linear regression equations that explain very small amounts of variance in the data are not to be trusted. They are inherently unstable. They are likely to change their effect in both magnitude and direction if different variables and different datasets are used. Any conclusions reached about such variables are built upon sand.

- Epidemiology can only establish a correlation, not a cause. To understand what causes an effect it is necessary to understand the mechanisms by which an independent variable, in this case, daylight, might affect the dependent variable, in this case either office worker performance, or retail sales, or school children’s progress in math or reading.

- Attempts to understand what these mechanisms might show that simply providing daylight is not a guarantee of success. Consistent with the view expressed in the Daylight Dividend review entitled “The Benefits of Daylight through Windows”, whether daylight has a positive or negative effect on the outcomes studied depends on how it is delivered. Daylighting that provides an even distribution of daylight that reveals an extensive view, that has controls to limit glare and thermal heat gain, and that does not introduce distraction, is likely to make a positive contribution. Daylighting that causes visual or thermal

> discomfort, or contributes to auditory difficulties, or introduces distraction, is likely to make a negative contribution.

The research reports do not make a strong connection between daylight and office productivity, retail sales or school children learning. The entire review of the Heschong-Mahone research is available on the program's website www.daylightdividends.org.

At the request of the Steering Committee, the LRC requested comments on its review from Lisa Heschong. Ms. Heschong's comments would be posted with the LRC review on the Daylight Dividends' website. Ms. Heschong has not provided any comments to date. If comments are received in the future, they will be posted.

Task 1.3: Focus Groups

Five focus groups were conducted in March and April 2003 across the country on behalf of the program with non-residential building owners, developers, managers and designers (architects, consulting engineers and lighting designers) for the purpose of understanding the knowledge, perceptions, feelings and barriers to the use of daylighting. The results of the focus groups helped to set the research agenda for the Daylight Dividends program.

The Management Summary and Implications are included here. The full report is included on the program's website www.daylightdividends.org.

MANAGEMENT SUMMARY

FOCUS GROUP RESEARCH PROJECT

BACKGROUND

The Daylight Dividends program was designed to increase the use of daylighting to improve indoor environmental quality and reduce electric lighting energy use. The Lighting Research Center (LRC) is coordinating the Daylight Dividends partnership. The partnership is lead by the U.S. Department of Energy and the New York State Energy Research and Development Authority, and partners include California Energy Commission, Connecticut Light & Power, Iowa Energy Center, and the Northwest Energy Efficiency Alliance.

Spectrum Associates was retained by LRC to conduct a series of focus groups to explore barriers to using daylighting in commercial, industrial and institutional buildings, and to identify ways to overcome these barriers. This document highlights the key findings and implications of the focus group study. A comprehensive presentation of the study findings follows the Management Summary.

METHODOLOGY

Spectrum Associates conducted five focus groups with a total of 48 participants. Specifically:

- two groups were conducted with building designers (i.e., architects, consulting engineers and lighting designers), one each in New York City and Portland, Oregon;
- two groups were conducted with "end-customers" of daylighting (i.e., building owners, developers and managers), one each in Charlotte, North Carolina and Des Moines, Iowa; and
- one group, held in Orange County, California, included a mix of building designers and end-customers.

All five focus groups were held in March 2003 and were moderated by Dr. Eliot Hartstone, president of Spectrum Associates. Dr. Hartstone used a moderator's discussion guide that was prepared by Spectrum Associates with assistance from and approval by LRC.

RESEARCH OBJECTIVES

The research objectives for the focus groups were to explore participants':

- Familiarity with and knowledge of daylighting.
- Overall feeling about the use of daylighting.
- Perceptions of who makes the daylighting decision.
- Perceptions of the key factors that determine whether daylighting should be used in designing a new building.
- Perceptions of the major benefits derived from using daylighting.
- Perceptions of the major barriers to using daylighting, and thoughts on effective strategies to overcome these barriers.
- Sources of information on daylighting, and suggestions on ways the U.S. Department of Energy and other agencies should get the word out about new advances in daylighting.

KEY FINDINGS

Familiarity with Daylighting

1. All participants indicated they were familiar with the term "daylighting," and said that it referred to bringing natural light into a building. About one-half of the participants took it a step further and said that by bringing in natural light, daylighting reduced the need for artificial light.

Overall Feeling About Daylighting

2. The overwhelming majority of designers and end-customers were positive, overall, about designing buildings to make <u>widespread</u> use of natural light.

3. Designers (3/4 "very positive") were more favorable than were end-customers (2/5 "very positive"), and Portland designers (9 of 10 "very positive") were the most favorable of any of the focus group sessions.

Who Makes Daylighting Decision

4. The final decision about using daylighting is a financial decision made by building owners/developers. However, designers frequently provide the inspiration for daylighting, and often it is their explanation of its benefits that overcome the owners'/developers' reluctance to spend the money needed for daylighting.

Key Factors Driving Daylighting Decision

5. Participants said that a main factor impacting the daylighting decision for a specific building is the desired use of the building, as some uses preclude daylighting and other uses benefit from daylighting. Other major factors cited were: the costs involved (capital costs required, and energy savings expected); the site location of the building (e.g., access to natural light, safety concerns); geographical location (e.g., West Coast most receptive); the time of day the building is being used; the need for security and privacy; the aesthetic fit with the surrounding buildings; and concerns about structural integrity.

6. Building uses that were described as <u>favorable</u> for daylighting were: schools; health care facilities; some types of offices; and manufacturing, retail and wholesale space. Building

uses that were described as unfavorable for daylighting were: offices with many computers; "big box" retail stores; specific areas in hospitals (e.g., surgery and x-ray rooms); research and laboratory facilities; military buildings; performance arts centers; sports facilities; art exhibits; and casinos.

Major Benefits of Daylighting

7. Participants said the major benefits of daylighting are: (a) the occupants of the building feeling better/more comfortable; (b) reduced energy consumption (i.e., less energy used and lower energy expenses); (c) increased employee productivity, including higher sales for retail stores; (d) improved building appearance/aesthetics; and (e) the increased marketability of the building to tenants or buyers.

8. A comparison across designers and end-customers reveals that designers focused primarily on the occupant's comfort and reduced energy consumption, while end-customers often emphasized benefits that directly impacted the owner/developer financially – increased productivity, improved building aesthetics, and increased marketability of the building.

Major Barriers to Daylighting

9. Participants said the greatest barrier to the expanded use of daylight is the capital costs involved (e.g., daylighting has very high upfront costs), and the second largest hurdle is problems with technology (e.g., daylighting requires a lot of technology which has yet to be perfected resulting in high maintenance costs).

10. Other important barriers raised by participants were: safety and security; the building's site location and access to sunlight; inconsistency in lighting across the building and during the course of the day; the added design/financial risks posed by using daylighting; confusion about daylighting to end-users; and overcoming the mindset of those involved.

11. Capital costs and technology problems/maintenance costs were viewed as the key barriers by both designers and end-customers. However, end-customers were more likely to emphasize concerns about safety and security and technology/maintenance costs, and designers were more likely to emphasize site location, confusion on the part of end-customers about the benefits of daylighting, the perceived added risks involved in daylighting since it is still a new approach to designing buildings, and the complications involved in designing daylighting.

Ways to Overcome Barriers to Daylighting

12. Participants' unaided suggestions for overcoming barriers to daylighting included:

    - Develop better and less expensive technology to address shading, dimming, heat gain, HVAC, glare, glazing and cleaning; and increase testing on new products before bringing them to market.

    - Increase education of professionals and end-users (e.g., describe daylighting options available, and show examples of daylighting working).

    - Provide financial incentives for installing daylighting (e.g., tax abatement, utility rebates, and grants).

  - Conduct more research on benefits of daylighting (e.g., definitive research on productivity).

13. Participants' reactions to nine different strategies for overcoming barriers to daylighting revealed that end-customers feel that substantiated proof of increased productivity would be the most effective strategy, while designers reacted most positively to better communications of benefits to owners/developers and developing better lighting controls and daylighting design tools for architects and engineers.

Current Information Sources on Daylighting

14. Participants said they most often get their information about daylighting from industry publications. Other current information sources are: word-of-mouth from engineers, architects, and lighting consultants; professional associations; seminars; Web sites; sales people/vendors; looking at buildings; trade shows; and studying for the lighting consultant examination.

Desired Communications Vehicles on Daylighting

15. While participants most often get their information through publications, responses to questions about preferred information sources revealed participants would like to be informed about new developments in daylighting through seminars, particularly those offering continuing education credits.

16. Participants also suggested informing them about upcoming seminars via e-mail, keeping the seminars short, and providing information on capital and maintenance cost implications. In addition to seminars, participants expressed interest in a dedicated Web site, e-mails, publications, experts speaking at conferences, and face-to-face meetings on new projects.

IMPLICATIONS

1. Designers and end-customers see considerable potential benefit to daylighting and, as such, there appears to be a great opportunity to significantly increase the use of daylighting. However, major barriers exist to daylighting expansion and much work is needed for this to occur.

The five focus groups revealed that designers and end-customers are positive about the potential of daylighting as they see many benefits to its use (e.g., occupants of the building feeling better/more comfortable and being more productive, reduced energy consumption, improved building appearance/aesthetics, and increased marketability of the building).

However, the focus groups also revealed several critical barriers to expanding the use of daylighting, and suggest that the increased use of daylighting will not occur unless these obstacles are clearly identified, understood, and addressed.

2. Many participants seemed to lack sophistication on the way in which daylighting uses natural light to achieve its goal. Education is needed in this area.

Participants typically referred to view windows and skylighting accessing direct light, and rarely discussed harvesting diffuse light to avoid the problems of glare and overheating. More education is needed on the manner in which natural light is used in daylighting.

3. While building owners, developers and managers are often positive about the concept of daylighting, financial considerations often result in their rejecting the use of daylighting for their buildings. As such, efforts to increase daylighting need to address building owner/developer fiscal concerns.

Our research suggests that designers are much more favorable about daylighting than are building owners, developers, and managers, due to their concerns about capital and maintenance costs associated with daylighting. Since building owners/developers were found to be the key decision-makers, efforts to expand the use of daylighting must address their concerns. Specifically, building owners/developers need to be educated on the: (a) potential for minimizing capital cost increases by committing to daylighting early in the design process; and (b) different ways they can achieve a return on their daylighting investment. It does not appear that appealing to more altruistic benefits derived from daylighting would be effective.

4. We believe it is critical to provide ammunition to designers that they can use in their efforts to "sell" daylighting to building owners/developers. Such ammunition must effectively address the owners'/developers' concern about capital cost and return on their investment.

Clearly, the final decision about using daylighting is typically made by the building owners/ developers. However, designers typically are the ones who raise the option of using daylighting to building owners/developers and the effectiveness of their argument is often critical in owners/ developers agreeing to use daylighting. As such, we believe a key factor in expanding the use of daylighting is providing designers with a strong case to address owners' fiscal concerns by documenting ways to minimize capital cost expenditures and achieve a high return on the their investments. Specifically, ammunition for designers could include: substantiated proof that daylighting increases occupants' productivity, including proof that daylighting increases retail sales; documentation on improved technologies that have eliminated or reduced maintenance problems and minimized maintenance costs; documentation of lower energy costs achieved through daylighting; and proof that daylighting increases the marketability of the building (sales and rental).

5. Efforts to expand the use of daylighting must also focus on advancing daylighting technologies. Part of the technology development process must include thoroughly testing new products and technologies before bringing them to market.

Focus group participants stated the need to improve daylighting technologies to overcome barriers to expanding the use of daylighting. Clearly, participants with hands-on daylighting experience have observed many technology problems. Some commented on technology problems resulting in daylighting systems being turned off by the end-user. Specifically, participants feel new technologies and products are needed to address shading, dimming, the connection of shading and lighting controls, heat gain, glare, glazing, and HVAC. Moreover, it is important to thoroughly test new technologies and products before bringing them to market to avoid problems after the daylighting system is installed.

6. Efforts to increase the use of daylighting must keep in mind that the use and location of the building determines whether a specific building is a good candidate for daylighting or not.

Participants in all five groups said that a main factor impacting the daylighting decision is the desired use of the facility. We believe efforts to encourage daylighting for buildings with specific uses inconsistent with daylighting would not only be unsuccessful, but also counterproductive to expanding the use of daylighting. Specifically, efforts to increase the use of daylighting should not be directed at: computer centers, specific areas in hospitals (e.g., surgery and x-ray rooms), research and laboratory facilities, military buildings, performance arts centers, sports facilities, art museums and galleries, and casinos.

In addition to building use, site location can also be a critical deterrent to daylighting. Specifically, daylighting should not be sought for buildings in areas with many high-rise buildings or in high crime areas.

7. Currently, designers and end-customers appear to have limited access to information on daylighting and rely mostly on publications. Efforts to increase daylighting require more systematic and diverse efforts to inform and educate target markets. It appears the most effective communications strategies would be holding daylighting seminars that offer continuing education credits, and developing a dedicated Web site.

Focus group participants said they most often get their information about daylighting from industry publications. However, participants said ideally they would get new information on daylighting through seminars, particularly those offering continuing education credits. The focus groups suggest that an excellent compliment to the seminars would be a dedicated Web site that provides: information on new products, pictures of buildings using daylighting, testimonials, utility costs, virtual tour of buildings using daylighting, and a calculator for determining expected savings on energy consumption.

Task 2: Conduct Research, Development and Demonstration Activities

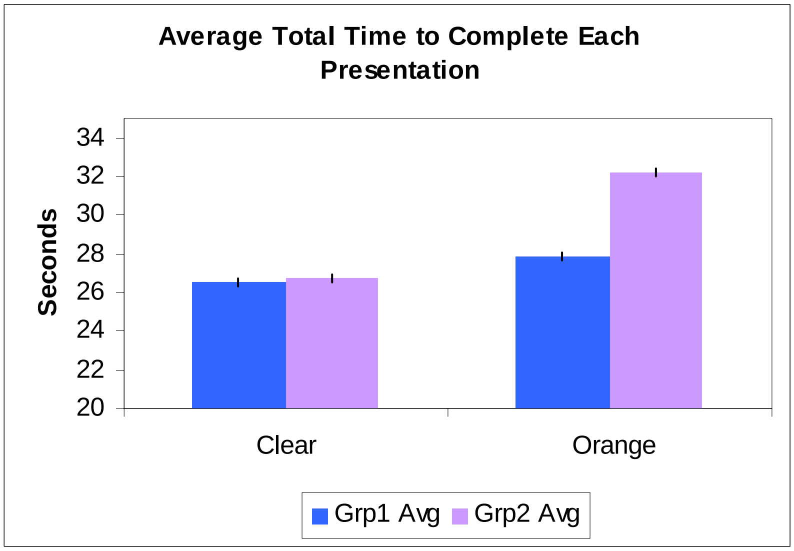
Task 2.1: Clarify the Links between Daylight and Health and Productivity

The LRC proposed and the Steering Committee approved the conduct of a study to test the hypothesis that daylight exposure in buildings affects occupant productivity through the human circadian system. This is an area of research identified in the human factor research review as needing attention. To test this hypothesis, the LRC needed to develop a means of measuring the amount of light effective to the circadian system that reaches the retina of people working in both windowed and interior offices.

A “daysimeter” was developed and lab tested. The proposed device is worn as a lightweight headset and has the proper spectral response for light affecting the circadian system. The “daysimeter” measures temporal patterns of short-wavelength light exposure throughout the day in addition to measuring user head position and overall activity. The proposed photometry/activity device is the first of its kind to accurately characterize retinal exposure to light as it impacts the circadian system as well as head movement behavior in people throughout the solar day. A full report on the development of the “daysimeter” is included on the program’s website www.daylightdividends.org. The daysimeter is being used in a major night shift workers study into their development of breast cancer. The study is being conducted by Harvard Medical School.

The LRC developed an experiment to test the hypothesis that daylight, through entrainment of the circadian system, reduces the amount of effort a person has to make to maintain a certain level of performance. LRC researchers were also attempting to establish a link between productivity and the amount of “circadian” light from daylight, measured using the daysimeter developed in Year One of the program. During the second program year, two groups of twelve subjects participated in the experiment. Subjects were asked to come to the lab before sunrise (05:00 hrs) and left the lab at 10:00 am, after sunrise. One dependent variable used to characterize performance, total time to complete each presentation, was subjected to a mixed-factor analysis of variance (ANOVA); groups (1 and 2) and glasses type (orange and clear) were treated as between-subjects independent variables, while font size (6, 8, 10, 12, and 14-point) was treated as a within-subjects independent variable. The other two dependent variables, correct presentations and total presented, were subjected to a between-subjects ANOVA; groups (1 and 2) and glasses type (orange and clear) were independent variables. The main findings of the laboratory study were:

- Performance, in terms of shorter time to complete the task, increased significantly with font size
- Performance, in terms of shorter time to complete each presentation, was significantly worse for those subjects with limited blue light exposure (orange glasses) than for those subjects with normal daylight exposure (clear glasses). A statistically significant interaction was found between the two types of glasses and the two groups of subjects (see figure below)
- Due to low statistical power, performance in terms of correct presentations completed and total presented was not statistically significant for either of the independent variables (groups and glasses type).
- Although not statistically significant, subjects with limited blue light (orange glasses) exposure took longer breaks than those with normal daylight exposure.



Group-by-glasses type interaction (average ± S.E.M.). In the clear safety glasses conditions, both groups took similar total time to complete each presentation, while when wearing the orange safety glasses, subjects in Group 1 had a shorter total time to complete each presentation than those in Group 2.

The full report is included in Appendix C.

Task 2.2: Daylighting Technologies

Impact of Dimming on Fluorescent Lamp Life

Daylight Dividends provided funding during Year One to examine issues surrounding the impact dimming has on fluorescent lamp life. Central to the issue of system performance is the fact that lamps were not designed to be dimmed. Indications from the Year One testing are the strategies and amplitude of electrode heating, when in the dimming mode, vary greatly from ballast manufacturer to manufacturer as do the electrode heating capacity of the lamps tested. There is no consensus among manufacturers as to the correct characteristics for either lamps or dimming ballasts that will create the necessary compatibility to ensure proper operation of these technologies without premature failures. The full report of findings is included in Appendix D.

Daylight Dividends provided a base of funding to interest other parties to join in further exploring issues surrounding lamps and dimming ballasts. At approximately the same time, NEMA formed a sub-committee on dimming. Daylight Dividends joined with NEMA to secure a US DOE grant to further study the compatibility issues between fluorescent lamps and dimming ballasts. The US DOE grant is $285,000 and the manufacturers are providing $228,000 in in-kind services. The ultimate goal is to recommend a series of metrics for the design and operation of fluorescent lamps used in dimming systems and for the dimming ballasts. This will be achieved by pilot testing lamp and dimming ballasts at fixed electrode heating and lamp current values and by conducting a life test. The following measurements will be taken.

- Electrode heating voltage (both ends of the lamp)
- Lamp current
- Electrode cold resistance
- Sum of squares heating current
- Filament voltage crest factor
- Lamp current crest factor
- Operating frequency
- Ballast case temperature
- Cathode fall voltage
- Lamp voltage
- Phase angle between lamp voltage and filament voltage
- Lamp cold spot temperature

This project will proceed outside the realm of Daylight Dividends. Results of the project will continue to be reported to sponsors.

Task 2.2: Daylighting Technologies

Daylight and HVAC Integration

The experiments conducted at the Energy Resource Station, Ankeny, Iowa attempt to determine the interaction between a building's lighting and HVAC systems for a building employing daylighting strategies. The experiments determined there is another building element, windows, which plays an equally important role in energy use and interacts with both the lighting and HVAC systems.

The experiments were conducted from August 22 to September 2, 2003 and from January 27 to February 8, 2004. These dates were chosen to represent summer and winter conditions in both temperature and sun conditions. . The experiments measured the HVAC and electric lighting energy used in identical sets of rooms where the only difference were the transmission characteristics of the windows. Rooms attempting to maximize the use of daylight to offset electric lighting had windows with visible transmittance (VT) of 73% and solar heat gain coefficient (SHGC) of 0.66 and rooms attempting to minimize solar gain had windows with VT of 23% and SHGC of 0.22. The results are limited by the two short time periods and the use of only two different window systems.

For the given test conditions and for the two test periods, the set of rooms with higher VT and SHGC window values used less total energy under all weather, solar and time of year conditions. The reductions in lighting energy and, corresponding, reductions in internal heat gain more than offset increased energy needs for cooling caused by increased solar heat gains through the clearer glass windows. Conversely, the increased solar heat gain in the winter assists in reducing heating energy needs. In these test cases, the clearer glass windows resulted in less total energy use than the highly tinted windows. However, there are many window types that were not tested. Different combinations of window glazing, tinting, reflective coatings and shading could have produced greatly different results. There exists a combination of these attributes that would produce optimum energy savings given the location of the building and size of the windows.

The second objective of the Iowa experiments was to test the installation and commissioning of the self commissioning photo sensor versus today’s commercialized photo sensors. The times required to install the self commissioning photo sensor were about the same as standard sensors. However, the commissioning times were drastically reduced. Based on these results, commercialization of a self commissioning photo sensor is a priority to further the acceptance of daylighting in buildings.

The full report is included in Appendix E.

Task 2.2: Daylighting Technologies

Dayswitch and Shade Controller Development

Market research has indicated building owners and designers desire to have cost effective, simple to use daylighting controls. To develop such controls, the Steering Committee approved funding for the conceptual development of two such devices. One is a simple, easy to install, low cost switch which can be connected to each light fixture to turn off the light when plenty of daylight is present. The second device is a shade controller to reopen shades after the sun will no long cause glare problems.

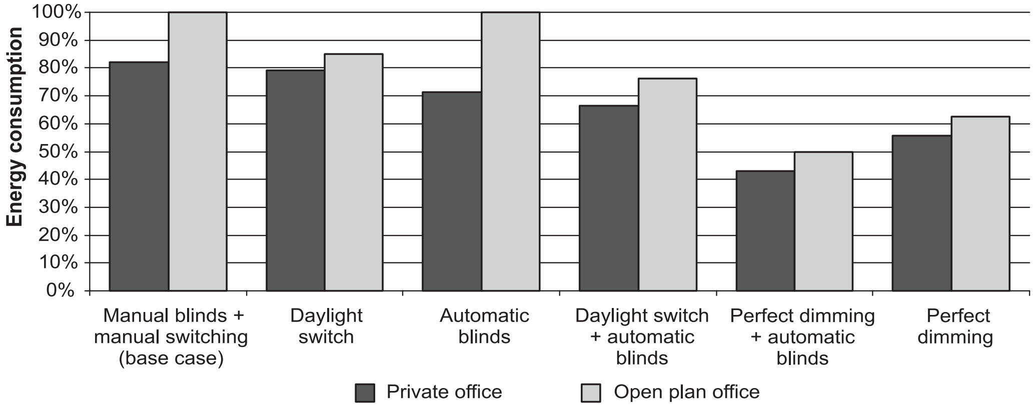
The proposed daylight switch is a device similar to a photosensor on a streetlight that will switch on and off the power to individual ballasts, depending on the availability of daylight. The device would be programmed to turn the lights on when the illuminance on the photocell drops below a certain value, and turn lights off when the illuminance due to daylight reaches a higher cut-off value. This value could be adjustable depending on the user's needs. The advantages of such a device include:

- lower initial cost because of the integrated installation of the photosensor and a cheaper, non-dimming ballast
- easy installation
- self-commissioning logic.

The proposed automatic blinds system is a device that opens window blinds once per day, either overnight or during lunch time. The blind-opening mechanism could either be a simple mechanical device or a solar-powered mini-motor programmed to activate during specific times of the day. The advantages of such a device include:

- complementary operation with other daylight harvesting systems already in use
- a design that makes use of the daylight that would have been lost
- potentially a simple and inexpensive add-on to window blinds technology
- easy installation and automatic operation
- manual operation possible at any time.

Assumptions of solar irradiance, blind position, blind operation behavior, and light switching behavior were combined with illuminance data and daylight factors to develop an algorithm for calculating the potential energy usages of six different systems in commercial private offices and open plan offices. Results show the combined usage of the proposed technologies perform with an average annual energy savings of 24% compared with manual switching and blinds operation in Albany, New York. Compared with a photosensor-operated dimming system, the proposed technologies combined show better performance during summer months. Comparisons also were made for the systems in six U.S. climatic regions. The results for Albany are shown on the following chart.



The full report on the findings was published in a peered reviewed article in *Lighting Research and Technology* and an abstract can be found on the program's website www.daylightdividends.com.

Additional funding ($75,000) based on the results of the Daylight Dividends conceptual work was secured from the California Energy Commission's Public Initiative Energy Research, Energy Innovation Small Grants program to develop a dayswitch prototype. The prototype was successfully completed at a price point that will allow for its cost effective use in new construction and in retrofit situations.

Further development, demonstration and evaluation of the DaySwitch^{TM} is made possible through a grant from NYSERDA. This work is ongoing.

Task 3: Seed Research

Task 3.1: Seed Research Projects

Seed research projects were designed to allow other research entities the opportunity to contribute meaningful research and information to overcome the barriers identified by the focus groups and the review of existing daylighting research. The process to solicit proposed research was to issue two requests for proposals, the first in year one and the second in year two, evaluate all proposals and award contracts to those proposals that best met the needs of furthering the use of daylighting.

Five seed research projects were funded during Year One of the Daylight Dividends program. These projects were completed during Year Two and Three of the program. Most of the research reports are posted on the Daylight Dividends website and are contributing to the use of daylighting. Each project is discussed below.

- Michael Nicklas, Innovative Design, Inc., Raleigh, NC – Developed a building designers' guide to the successful use of daylighting in schools. The guide, *Guide for Daylighting Schools,* was completed during Year Two of the program and can be found on the Daylight Dividends website.
- Dr. Martin Moeck, Pennsylvania State University - Development of a series of tables to determine glazing strategies, lighting controls and top lighting sizing to maximize energy savings for top lighting strategies in multiple climate zones through use of integrated software. The report was completed in February 2005 and the full report can be found on the Daylight Dividends website, www.daylightdividends.org. The primary conclusions from this study are as follows.
    - The glazing size should be determined on the basis of total energy use rather than by a specific daylight factor.
    - Building toplighting strategies can save overall building energy consumption in a variety of climates compared to the base case with an opaque roof, with electric lighting controls.
    - In regards to lighting control, switching performs as well as dimming does.
    - The energy performance of toplighting strategies is very sensitive to weather and the toplighting design must be based on local weather data.
    - As aperture size decreases, overall building energy consumption also decreases up to a certain point. Therefore, successful toplight design depends on small aperture size.
- Professor G. Z. Brown, University of Oregon - Development of a mechanical shade opening system to maximize the availability of daylight. The prototype shade controller has been developed and has undergone a small field test. The results of the field test are reported under Task 5. No final report of the mechanical shade opening system is available. The device is still going through the patenting process and the developers consider the technical information proprietary.
- Dr. Jong Jin-Kim, University of Michigan - Conducted research to determine the value of windows in building to the real estate market. Research into the value of windows has been completed in three real estate markets, New York City, San Francisco and Chicago. Results of the data collection and research are posted on the Daylight Dividends website. A summary table of the results is presented below. The full report can be found on the program's website, www.daylightdividends.org.

Is view a factor in pricing structure?

	Percent saying "Yes"	
Hotels (n=21)	48%	$15 - $70 per night for those that price by view
Apartments/condos (n=15)	87%	One condo reported $15,000 - $70,000 increase with view
Offices (n=22)	73%	

- Dr. Herbert Eckerlin, North Carolina State University - Identified the barriers to the wide acceptance of daylighting in schools and identified strategies to overcome these barriers.

Four additional seed research grants were awarded during Year Two of the program. Final reports on these efforts have not been received as of the publication of this final report. The LRC will issue these reports to sponsors and place them on the website as soon as they are received. The four projects are:

- Dr. Ihab Elzeyardi, University of Oregon – Relationship between daylighting quality and sick leave. Examination of the biophilia effect. The report is posted on the program's website, www.daylightdividends.org.
- Professor Kevin Van Den Wymelenberg, University of Idaho - A working plan to develop regional daylighting labs and outreach centers. The guide to the development of regional daylighting labs is completed. The results are included on the Daylight Dividends program website.
- Dr. Martin Moeck, Pennsylvania State University - Development of a series of tables to determine glazing and shading strategies to maximize energy savings for side lighting strategies in multiple climate zones through use of integrated software. The full report on sidelighting strategies is posted on the program's website.
- Professor G. Z. Brown, University of Oregon - Daylighting design tools. This project will create daylighting design tools that are dramatically simpler to use and quicker to learn than existing tools, and are oriented to creating rather than analyzing daylight-revealed spaces. This will be accomplished with a computer-based system that distills project information (climate, site, use, design), and generates a customized tool that can be printed and overlaid on the design drawings, delivering it instantly via the web.

Task 4: National, State and Regional Daylighting RD&D Activities

This task calls for the collection of research, development and demonstration activities of others involved in promoting or enhancing the use of daylighting. There are no specific deliverables for this task. However, the LRC continues to review articles, research, etc. to update sponsors on research being conducted by others and to include interesting and compelling research via links to the Daylight Dividends website.

Task 5: Demonstration/Evaluation Projects

Task 5.1: Identify Case Studies or Technology Demonstrations

During Year One, three case study sites were selected for evaluation of daylighting designs, strategies and lighting control technologies and approved by the Steering Committee. These sites included a school, a library and an office building. The evaluations of these sites occurred in program Year Two and are reported under Task 5.2.

The Steering Committee approved the selection of demonstration and/or evaluation of emerging or existing daylighting technologies during program Year Two for implementation during Year Three. The LRC reviewed different technologies and recommended the following three for demonstration and evaluation. The Steering Committee approved these technologies.

- Conduct a demonstration and evaluation of the mechanical shade control device developed under the seed research grant with the University of Oregon. This evaluation occurred at the University of Oregon and at the Lighting Research Center. Four shade controls were installed on east, south and west facades. Measurements of before and after conditions were collected on shade use, energy and occupant satisfaction.
- Conduct a demonstration and evaluation of the Dayswitch developed as part of the Daylight Dividends program and under a separate grant from the California Energy Commission. This evaluation occurred at the University of Oregon and at the Lighting Research Center in conjunction with the shade controller. Four Dayswitches were installed. Measurements of before and after conditions were collected on energy and occupant satisfaction.
- Update the National Lighting Product Information Program (NLPIP) Specifier Report on photosensors. This effort was funded jointly by Daylight Dividends and NLPIP. Many new and improved photosensors have entered the marketplace since the first Specifier Report was published seven years ago. Evaluation of these technologies will assist in their introduction and use by building owners and designers. The final report is due in September 2006 as part of the NLPIP program.

Task 5.2: Conduct Case Studies and Evaluations of Technologies

Three case studies were completed during Year Two and published on the Daylight Dividends website. These studies include extensive energy and occupant evaluations of each site. The case studies can be found on the program’s website www.daylightdividends.org.

- Smith Middle School, Chapel Hill, North Carolina – This school employs south facing roof monitors to harvest the available daylight. Overhangs above the monitors and interior translucent baffles prevent glare. Lighting energy savings is approximately 70% in daylit areas of the school. Cooling savings of 20% are achieved primarily by reducing the internal heat gain of the electric lights. Teachers and students expressed complete satisfaction with the daylighting system. One teacher indicated she thought she “died and went to heaven” after her experience with the daylighting design.

- Harmony Library, Fort Collins, Colorado – Daylight enters this single story building primarily through clearstory windows located on all four building exposures. The majority of the glass is facing either north or south. The electric lights are controlled with an open loop outdoor photosensor system that turns light fixtures off when plenty of daylight is present. Lighting energy savings are 36%. Librarians and library users indicated satisfaction with the daylighting system. No complaints were registered regarding the lighting switching control system.

- TomoTherapy, Madison, Wisconsin – This is an office/light assembly building that employs a daylighting strategy in the open office areas (about 12,000 square feet). The original lighting design has a power density of approximately one watt per square foot. At these levels, it is difficult to cost justify the use of the dimming system employed. However, the building occupants thoroughly enjoy the views from the large expanses of glass. There are some glare issues because most of the glass faces either west or east. Glare is controlled by the use of manual blinds. Because of the desire for a view, blinds are reopened as soon as the sun no longer creates glare.

The three technology demonstrations or evaluations were conducted during program Year Three. Final reports of the DaySwitch demonstration are included on the program's website, www.daylightdividends.org. In general, the DaySwitch installations were easy and straightforward. Energy savings was very installation specific ranging from 11.6% to 67% compared to the lights remaining on all the time. Occupants were accepting of switching the lights off and on once or twice per day. Additional development of the DaySwitch must be achieved and a larger demonstration of the device must occur prior to the full commercialization of the DaySwitch.

The mechanical shade control device was also demonstrated and evaluated. The final reports of the evaluations can be found on the program's website. The addition of the mechanical shade controller did increase energy savings over the use of the DaySwitch alone. An additional 30% savings was achieved. Operational issues are present in the alpha prototype that need to be corrected before the shade controller can be considered for commercialization. When the shades opened automatically, it was with a loud "snap" that startled occupants.

The evaluation of current photosensor technologies included extensive testing of fifteen photosensors. The Daylight Dividends Steering Committee agreed to fund 50% of the research costs ($75,000) to update the National Lighting Product Information Program's (NLPIP) Specifier Report on photosensors. The last Specifier Report on photosensors was published in 1998. Since then newer technologies have been introduced to the marketplace. The update research is testing 15 photosensors of both the dimming and switching varieties. Results will be published in September 2006. The Daylight Dividends portion of the funding was used to establish all the testing protocols and purchase the photosensors. NLPIP will complete the testing and publish the results.

Task 6: Dissemination, Education, Outreach

Task 6.1: Disseminate Results to Sponsors

Monthly reports have been circulated to all sponsors as have the results of all research conducted. During the semi-annual Steering Committee meetings, research results and/or updates were presented by the primary researcher and results discussed by the Steering Committee. In all cases, the Steering Committee accepted the research results prior to public dissemination. Year One and Year Two annual reports were developed and disseminated to all sponsors and other interested parties. This final report summarizes all three years of the program's efforts and is the culmination of the dissemination of the program's results.

Task 6.2: Dedicated Website

The LRC, with input and guidance from the Steering Committee, developed and launched a website that promotes the use of daylight to a public audience. The LRC has published the existence of the website with the many search engines and with program Sponsors and LRC Partners. During its two plus years in existence, the Daylight Dividends dedicated website has received 59,451 visits either through the LRC's website or directly into www.daylightdividends.org. There have been 18,353 unique visitors, spending on average 6.5 minutes on the site.

The website includes areas for designers as well as building owners, developers and managers. Within the designers' area, one can find information regarding technology issues like windows, shades and lighting controls, design tools and successful applications of daylighting. The building owners' area emphasizes the effects of daylighting on productivity and occupant well being and the value of buildings that incorporate daylighting. The reports of the focus group findings and the review of existing and on-going research on the human benefits of daylighting are also available through the website. A new section was added which includes all the research reports generated by the Daylight Dividends program.

A revised website design was developed in Year Three and placed in service in February 2006. Its purpose is to increase the number of visitors to the site and make site navigation easier. The new home page is pictured below.

September 24, 2004
Smith Middle School Case Study

August 19, 2004
Guide for Daylighting Schools
A comprehensive brochure addressing key design considerations for using daylighting in schools.

June 9, 2004
LRC develops Daysimeter to measure circadian response to daylighting

Daylighting reduces the need for electric light by introducing natural light into a building.

The Daylight Dividends program was established to build market demand for daylighting as a means of improving indoor environmental quality; to overcome technological barriers to effectively reap the energy savings of daylight; and to inform and assist state and regional market transformation and resource acquisition program implementation efforts.

SPONSORED BY:

California Energy Commission
Connecticut Light & Power
Iowa Energy Center
Lighting Research Center
North Carolina Daylighting Consortium
Northwest Energy Efficiency Alliance
NYSERDA
US Department of Energy

Task 6.3: Publicize the Value of Daylighting

A major undertaking of publicizing the value of daylighting was the development of the Daylighting Controls Practicum and training trainers from around the country to conduct the control classes. As part of this effort, the LRC developed a daylighting controls simulator which allows trainers and students to experience, first hand, the installation, adjustments and operations of different daylighting control strategies. Donations of controls and dimming ballasts were received from Watt Stopper, SensorSwitch, PLC Multipoint, Universal and OSRAM Sylvania. Immediate feedback as to how the control system is performing is provided via a computer data acquisition program that displays task illuminance, artificial sun light levels, power levels of the lamp and ballast and control voltage to the ballast.

The practicum outline of instruction is included in Appendix F. Each of the thirteen practicum attendees was given a complete set of training manuals and eight control simulators have been shipped to the sponsors. The hands on training received very positive reviews from all the attendees. Throughout program Year Three the practicum or parts of the controls training have been presented at least eight times across the country.

Additional outreach activities occurred through presentations to major regional or national audiences. The following outlines those presentations.

- Association of State Energy Research and Technology Transfer Institutions – March and October 2003
- California Energy Commission, California utility personnel, California lighting consultants and lighting manufacturers – April 2003

- Electro Expo, Cleveland, OH – April 2003
- American Society of Heating, Refrigeration and Air Conditioning Engineers 90.1 Sub-committee on Lighting and Power – June 2003
- Western New York Chapters of American Institute of Architects, Efficient Buildings Association and U.S. Green Building Council – September 2003
- Eastern New York Chapters of American Institute of Architects, Efficient Buildings Association and U.S. Green Building Council – October 2003
- Northwest Energy Efficiency Alliance, Controls Summit, June 2004 – control manufacturers, daylighting experts, building designers
- American Counsel for an Energy Efficient Environment, Summer Study, August 2004 – demonstration of daylighting controls simulator to energy efficiency experts from around the globe
- Edison Electric Institute, National Accounts Conference, September 2004 – Energy managers from major retail, hospitality and supermarket chains and utility account executives.
- Two presentations at the LightFair Daylighting Institute occurred in April 2005. Mark Rea and Mariana Figuiero presented their findings on daylighting and health issues and Russ Leslie and Andy Bierman presented information from the Daylighting Controls Practicum.
- Russ Leslie made a presentation to the national facilities managers group for private secondary schools in April 2005
- Presentations regarding the Daylight Dividends program’s efforts and results were presented at LightRight 6 in May 2005 to an international audience of lighting and energy efficiency experts.
- Russ Leslie, in September 2005, made a presentation on the use of daylighting and design integration to the northeast region of AIA. Andy Bierman also addressed this audience discussing daylighting controls.
- Russ Leslie participated on a daylighting panel at E-Source’s annual members meeting in Boulder, CO in September 2005.

Appendix A: Steering Committee Meeting Notes

MEETING NOTES
DAYLIGHT DIVIDENDS
STEERING COMMITTEE MEETING
JANUARY 15, 2003

The first Steering Committee meeting of the Sponsors and Partners for the Daylight Dividends research program was held on January 15, 2003 at the National Laboratories offices, 901 D Street, SW, Washington, DC. Present representing the Sponsors on the Steering Committee were the following.

Donald Aumann	California Energy Commission (CEC)
Amy Cortese	Northwest Energy Efficiency Alliance (NEEA)
Samuel Fankhouser	The Connecticut Light & Power Company (CL&P)
John House	Iowa Energy Center (IEC)
Joel Chaddock	U. S. Department of Energy (US DOE)
Russ Leslie	Lighting Research Center (LRC)
Marsha Walton	New York State Energy Research & Development Authority (NYSERDA)

Partners and others present included the following.

Joel Loveland	Lighting Design Lab & NEEA
James Brodrick	US DOE
Peter Morante	LRC
Edward Petrow	Lincoln Technical Services (consultant to US DOE)
Stephen Kalland	North Carolina Solar Center
Donna Stankus	North Carolina Solar Center

Each Sponsor and Partner representative presented a short overview of daylight activities underway at their respective companies, agencies or centers. This was followed by Russ Leslie reviewing the objectives and deliverables of the program. Russ stressed the need to reduce the credibility gap of the current information regarding daylighting so the building design community and building developers, owners and managers can make informed decisions about using daylighting.

A discussion of deliverables by the Sponsors ensued. It was agreed the deliverables lacked specificity regarding research needs for the design of buildings. Possibly a “Design Advisory Board” should be established to determine what effect the outcome of the program’s research will have on designing for daylighting. It was agreed to provide additional emphasis on the design side of buildings as projects are chosen for demonstration projects and other research are determined later this budget year.

IEC also indicated it could not fund any of the “Seed Research” efforts. This is true of US DOE, also.

General discussions also were held regarding what metrics should be used to gauge success of the program. It was agreed the LRC and Jim Brodrick, US DOE, would develop draft metrics for presentation to the Steering Committee before their next meeting.

Operating Plan

The Operating Plan dated December 11, 2002 was discussed, modified and unanimously approved after discussions regarding changes to the seed research by the Steering Committee. Modifications include dropping the Scope of Work section from the operating plan, adding the words “and Partners” to the Role of the LRC section in the bulleted item work with Sponsors and Partners to seek additional funding as appropriate and modify the Seed Research section to include approved changes to the Seed Research proposal. Included in this section will be a reference that IEC and US DOE funds will not be used for seed research.

Technical Advisory Board

Discussions on candidates for the blue ribbon panel to review human factor research regarding daylighting benefits produced the following:

- Dr. Peter Boyce, LRC, will chair the board.
- Dr. Boyce will contact Dr. Judith Heerwagen, PNNL, Dr. Vivan Loftness, Carnagie Melon and someone from the health field to serve on the board.
- Dr. Boyce will also select a fifth person to serve on the board.
- The names of the individuals selected to review research will be submitted to the Steering Committee for concurrence.

The work necessary to review human factors research concerning daylighting will commence immediately following acceptance of board members. The board should review the work currently underway by Carnegie Melon under the sponsorship of NEEA.

Roundtable Research

Only one proposal was received to conduct focus groups from the four companies that indicated a desire to bid. The Steering Committee reviewed the proposal and made the following modifications. Building designers focus groups will be conducted in Portland, OR and New York City instead of San Francisco and New York City. End use customer focus groups which will include developers, building owners and building managers will be conducted in Des Moines, IA, Charlotte, NC and a city in California to be named by Don Aumann instead of Hartford, CT, Seattle, WA and Tampa, FL.

The Steering Committee approved unanimously the proposed roundtable research to be conducted by Spectrum Associates with the above modifications. Sponsors will be invited to participate in the development of the facilitators guide and participant screening document and Sponsors and Partners will be invited to attend all of the focus groups. Sponsors will each receive video tapes of each focus group.

Daylighting and Health Field Study

The LRC proposed to conduct a light and health study to examine the effect of light during the day versus light at night on breast cancer. A lengthy discussion followed. It was explained this study could open the door to additional funding from the National Institute of Health. Most Sponsors believed this research should go forward as long as the research was in keeping with the procedures of NIH and met the needs for possible future funding.

A formal vote of Sponsors was taken to conduct this research with funds from the Daylight Dividends program. IEC, CL&P, NYSERDA, CEC and NEEA voted to fund the research. US DOE voted against the research subject to an internal review of DOE policies regarding the use of individuals in health research. Joel Chaddock, US DOE is to look into the policies and report back to the Steering Committee. Since US DOE has 50% of all votes, the motion was defeated. US DOE may reverse its vote if it deems its policies will allow it to fund health related research on individuals.

Seed Research

Major changes to the original seed research plan were recommended because of the tardiness in commencing the Daylight Dividends program. It was determined the time remaining in year 1 of the program would not allow sufficient time to complete the deliverables contained within the contract with US DOE. Seed research will still provide funding for nine projects but request for proposals will be in two groups rather than three. The initial request for proposals will be issued after the completion of the focus groups and report of the Technical Advisory Board. Both these efforts will identify needs for additional research in daylighting issues and will set the direction for the seed research.

The Steering Committee unanimously approved the modifications to the seed research. The LRC will request a modification to the program’s deliverables from US DOE.

Lamp/Dimming Ballast Compatibility Research

The contract with US DOE requires the year 1 deliverables to include initial research into the compatibility of fluorescent lamp life, color, color change, etc. with dimming ballast technologies. The LRC proposed to conduct this initial research for $106,500. The Steering Committee revised the budget for this activity to $110,000 and included additional tasks. Two tasks were added. The LRC will discuss lamp dimming ballast potential problems with building designers, owners and installers to gain any anecdotal information. The LRC will also investigate any standards major lamp manufacturers place on their products used in a dimming capacity.

The Steering Committee, with the modifications to the budget and tasks, unanimously approved this research to be conducted by the LRC.

Data Collection Plan of Partners' Daylighting Information

Russ Leslie presented a first cut of information gathered from Sponsors' and Partners' web sites concerning daylighting. He asked each Sponsor and Partner to review the information and provide comments back to the LRC. Sponsors and Partners are to notify the LRC of any web based information they wish to include as links to the daylight web site that are not included as part of the Task 4 draft dated 1-13-03.

Operating Budget and Allocations

A proposed year 1 operating budget was prepared and distributed by the LRC. Current revenues total $591,318. The Steering Committee modified the allocation of the budget to include an additional $3,500 for the lamp/dimming ballast compatibility research. Via a previous vote to not fund the light and health initial field study at this time, the $70,000 for this task was eliminated. The Steering Committee elected not to reallocate $66,500 of the budget at this time.

Total allocations approved by the Steering Committee totaled $524,818. The amount to be allocated is $66,500. The Steering Committee unanimously approved the budget and allocations with the above modifications.

Next Steering Committee Meeting

The next scheduled Steering Committee meeting will be held on May 30, 2003 at the Lighting Design Lab, Seattle, WA. The meeting will be hosted by NEEA and the Lighting Design Lab. Dress for all Steering Committee meetings will be business casual.

MEETING NOTES
DAYLIGHT DIVIDENDS
STEERING COMMITTEE MEETING
MAY 30, 2003

The second Steering Committee meeting of the Sponsors for the Daylight Dividends research program was held on May 30, 2003 at the Lighting Design Lab, Seattle, Washington. Present representing the Sponsors were the following.

Donald Aumann	California Energy Commission (CEC)
Amy Cortese	Northwest Energy Efficiency Alliance (NEEA)
John House	Iowa Energy Center (IEC)
Joel Chaddock	U.S. Department of Energy (US DOE)
Russ Leslie	Lighting Research Center (LRC)

Present representing Sponsors via phone connection:

Peter Douglas	New York State Energy Research and Development Authority

Others present included the following.

Dona Stankus	North Carolina Solar Center
Peter Morante	LRC
Andrew Bierman	LRC
Peter Boyce	LRC
Joel Loveland	Lighting Design Lab & NEEA
Dale Brentrup	University of North Carolina at Charlotte
Marsha Walton	NYSERDA (via phone)

Absent from the meeting was representation for Connecticut Light and Power Company. However, Samuel Fankhouser provided voting guidance on two issues. CL&P accepted the proposal for the Dayswitch and rejected the proposal for the auto-open daylight blinds.

The North Carolina Solar Center, as coordinator of the North Carolina Daylighting Consortium, has committed $5,000 of funding with the possibility of committing an additional $5,000 upon approval of the North Carolina Department of Administration, State Energy Office to the Daylight Dividends program. In accordance with the Operating Plan of the program, a majority of the Steering Committee voted to include the North Carolina Solar Center as a full voting Sponsor of the Daylight Dividends program and a member of the Steering Committee. With the addition of the North Carolina Solar Center (NCSC) as a Sponsor, the weighting of each Sponsor's vote changes as follows based on a NCSC contribution of $5,000. If NCSC's contribution changes to $10,000, the weightings will change again.

US DOE	50%
NYSERDA	18%
CEC	9%
CL&P	9%
IEC	4%
NCSC	1%
NEEA	9%

Focus Group Report

Eliot Hartstone, President, Spectrum Associates presented the results, conclusions and recommendations from the five focus groups conducted by Dr. Hartstone for the Daylight Dividends program with non-residential building designers, owners, managers and developers. A copy of the final report and the presentation will be electronically delivered to each Sponsor under separate cover. Recommendations from Sponsors included the following.

- Treat building designers differently from building owners, developers and managers in two broad market segments.
- Review the work of Mark Jewell on the financial analysis of daylighting. His information can be accessed through NEEA's Better Bricks web site.
- The submittal to US DOE will include comments that the findings of the Daylight Dividends focus groups are similar to regional market research studies conducted by NEEA and the Energy Center of Wisconsin.
- The compilation of design tools was suggested with funding from next program year's budget. A means of beginning this process maybe to conduct a meeting of experts.
- The Daylight Dividends website should include the entire report along with a synopsis of the findings and what the program intends to do in response to the findings.
- US DOE requested the standard disclaimer regarding the findings be placed on the report. This will occur on the final version that will be e-mailed to all Sponsors and submitted as the formal completion of Task 1.3.

The Steering Committee voted to accept the focus group report. The LRC will submit the report, with the appropriate disclaimer, to US DOE as the completion of Task 1.3.

Peer Review of Human Factors Research

Dr. Peter Boyce, LRC, presented the results of the Peer Review effort on human factors research that has been conducted regarding the benefits of daylighting. Since the LRC encountered some troubles in communicating the draft report to Sponsors, no formal vote was conducted on acceptance of the Peer Review report. Sponsors requested substantive comments from reviewers be included in the report and that an introduction section be written. This introduction section will include the purpose of the report, reviewers, program sponsors, methodology in compiling the report and the standard disclaimer required by US DOE. A review of the wording "large amount of light" when referring to visual and task performance will be conducted. The final report will be submitted to Sponsors for comments and acceptance.

Lamp/Dimming Ballast Update

Mr. Andrew Bierman, LRC, reviewed the progress being made on the lamp/dimming ballast issues and explained the operation of the self commissioning photo sensor. A copy of Mr. Bierman's presentations is being sent via e-mail.

Daylight Dividends Website

A presentation was made regarding a dedicated Daylight Dividends website. Comments from Sponsors included:

- The site must have less of an LRC look and more of its own look, but should clearly identify the LRC and Sponsors in order to validate the site as quality, objective information.
- The initial page must direct building designers to their interests, while directing building owners to theirs. These two primary market segments must be treated separately because they have different interests.
- Individuals referencing the web page for general information regarding daylighting must also be directed to pages concerning their interests.
- The desk lamp image on the proposed home page is not necessary.

Daysimeter

The LRC presented and recommended approval of the development of a “daysimeter” to measure light and activity based on the human circadian system. The device is indispensable for any future studies attempting to test the hypothesis that daylight exposure in buildings affects occupant productivity through the circadian system. Based on the Peer Review, circadian system productivity affects may be one of the few means of accurately measuring daylighting’s affect on productivity.

US DOE pointed out the deliverable for the productivity and daylighting task is to conduct an “experiment that will help clarify the links between daylight and health and productivity…”. The LRC proposal, while addressing a need to develop an instrument to measure the link between daylight and productivity and health, does not directly address the deliverable of conducting an experiment. Sponsors agreed with US DOE that the proposal regarding daylight and productivity needs to be expanded to include, as its main objective, an experiment that utilizes the “daysimeter” to measure daylight and productivity links. The LRC will rewrite the proposal and change the title to reflect the Sponsors’ comments. The proposal will be sent to Sponsors for comment and approval along with approval for the allocation of funds to conduct the experiment and development of the “daysimeter”.

Photosensor/HVAC Testing @ IEC

A proposal to conduct a series of tests to measure the effects of daylighting on light and HVAC energy use under different glazing and shading conditions was proposed by the LRC and IEC and accepted by the Steering Committee. The tests will be conducted this summer. The hypothesis to be tested is the use of daylight does not increase total energy use for both lighting and HVAC. The Steering Committee also approved $6,500 from the unallocated funds be spent to conduct analysis of the data to be collected. It is suggested a follow up test be conducted during the winter using funds from the next program year’s budget.

“Dayswitch”

The LRC proposed to develop a conceptual design, conduct research and simulations and develop a commercialization prospectus of a low cost lighting switch that reduces electric energy when daylight is sufficiently high to provide visual stimulus. This is an alternative to the high priced full dimming ballast method of employing daylight and may offer a reasonable cost effective alternative.

The Steering Committee approved the project with funding coming from next year’s budget on the condition that the LRC conduct a complete literature search for any similar devices.

Self-Powered, Auto-Open Daylight Blinds

The LRC proposed to develop a conceptual design, conduct research and simulations and develop a commercialization prospectus of a self-powered, auto-open blind system that alleviates the problem of people rarely reopening their blinds once they have closed them. This cost effective device will increase the savings possible from daylighting.

The Steering Committee approved the project with funding coming from next year's budget on the condition that the LRC add to its proposal a task to explore other developing technologies especially those being developed by Dr. Larry Silverberg at North Carolina State University and Dr. G. Z. Brown at University of Oregon.

Seed Research

Five possible research areas were developed by the LRC for funding of seed research projects based on the outcomes of the focus group and peer review research. These included:

1. Design, build a prototype and evaluate a cost effective window comfort system that maximizes the availability of daylight for interior building illumination and minimizes discomfort from glare, brightness, etc. caused by daylight inside a building. The window comfort system can approach the problem by developing window (glazing), blinds, shades or structural solutions.
2. Conduct a survey to determine any increase in building value because of the use of daylight. Determine, on a regional basis, if buildings deploying daylighting have a greater resale value and, in rental property, have higher occupancy rates, lower turnover of tenants and lease prices higher than average than non-daylit buildings.
3. Quantify the importance non-residential building occupants place on the need to be in contact with nature/the outdoors (the biophilia hypothesis) while working within a building. Quantify the value (what is it worth to be able to see the outdoors) of this contact with nature.
4. Develop both a written and electronic version of a guide to daylighting that building owners could follow to implement daylighting strategies in existing buildings i.e., 10 simple things to capture daylighting in existing buildings. This guide could discuss simple blind positioning or the addition of lighting controls at the time of building renovation.
5. Compare and contrast approaches to skylighting buildings with different purposes (offices, retail, warehouse, school). What types of buildings can be served through the use of skylights to provide daylighting? What types of skylights are employed and why? How do they work to provide light and comfort (reduce glare) to building occupants? How do they interface with artificial lighting systems? How well do these interfaces work?

To these suggested research areas, the Steering Committee added to area five, compare and contrast approaches to skylighting "or top lighting" and a sixth area, investigate barriers to the use of skylighting and how to effectively overcome these barriers. Funding levels will read that "up to" $20,000 per project is available from the Daylight Dividends program and must be matched at least one-for-one from other funding sources. The other funding sources can include "in-kind" services for the value of the direct billable costs. However, additional funding sources will be encouraged.

With the addition of the above suggestions, the Steering Committee approved the seed research proposal and is requiring the LRC to solicit proposals. The LRC will request of Sponsors people who will review and rank proposals once received.

Demonstration Projects

Task 5 of the Daylight Dividends program requires three demonstration projects be selected and the criteria for their evaluation be developed during Year One of the program. To that end, the LRC recommended areas of research for the demonstration projects. These included:

- The demonstration sites will show the acceptability, comfort and energy use of day lit schools, offices or retail buildings.
- The site can showcase the use of a technology such as a window treatment or lighting controls.
- The site can demonstrate the use of a design method that can be duplicated by other designers wanting to use daylighting.
- The site can show how the proper design can save the amount of total energy consumed in the building and/or how to keep capital costs of day lit buildings approximately the same as common building designs.
- This study type would be about the people who occupy the building, their comfort in working in a day lit building, do they feel more productive, why, is there a feeling of connection with the outdoors. It is not meant to be a statistically accurate measure of productivity. Rather, this type of study would attempt to start to explore the biophilia hypothesis.

The Steering Committee accepted these areas of research and requested the LRC to solicit possible evaluation sites. The LRC will solicit sites initially from Sponsors. Only if sites cannot be found that meet the needs of the program will the LRC solicit additional sites from other than Sponsors. The LRC will develop consistent evaluation criteria for each project and will share these criteria with Sponsors.

Revised Budget

Attached is a revised budget that reflects the $5,000 NCSC sponsorship as revenue and the allocation of $6,500 to conduct analysis of data collected at IEC.

Next Steering Committee Meeting

The next scheduled Steering Committee meeting will be held on October 24, 2003 at the Lighting Research Center, Troy, NY. The meeting will be hosted by the LRC. Emphasis of this meeting will be to review all deliverables of Year One and to set the research agenda and budget for Year Two. Dress for all Steering Committee meetings will be business casual.

MEETING NOTES
DAYLIGHT DIVIDENDS
STEERING COMMITTEE MEETING
OCTOBER 23-24, 2003

The third Steering Committee meeting of the Sponsors for the Daylight Dividends research program was held on October 23rd and 24th, 2003 at the Lighting Research Center in Troy, New York. Present representing the Sponsors were the following:

Joel Chaddock	U.S. Department of Energy (US DOE)
John House	Iowa Energy Center (IEC)
Peter Douglas	New York State Energy Research and Development Authority (NYSERDA)
Marsha Walton	NYSERDA
Joel Loveland	Northwest Energy Efficiency Alliance (the Alliance)
Samuel Fankhauser	Northeast Utilities (CL&P)
Russ Leslie	Lighting Research Center (LRC)
Dona Stankus	North Carolina Solar Center (NCSEA)

Present representing the Sponsors via conference call:

Donald Aumann	California Energy Commission (CEC)

Others present included the following:

Peter Morante	LRC
Andrew Bierman	LRC
Conan O'Rourke	LRC
Lei Deng	LRC
Ramesh Raghavan	LRC
Cy Eaton	LRC
Nick Pandya	LRC
Wendy Fujinaka	LRC

The DOE (Joel Chaddock) would like to abstain from voting, and will not exercise the DOE's 50% of the votes in the Steering Committee meeting. The DOE is only present to ensure the project stays within the scope outlined in the contract.

Daysimeter

Andrew Bierman, LRC, presented the progress made and a prototype of the daysimeter. The demonstration showed the device logging the sensitivity and light levels of the circadian and photopic spectrums, and activity (the tilt of the head, head movements, etc.). The device should be completed in a month or so. The logging device will be integrated, the circuitry will be miniaturized, and the device will attach to the ear of the wearer.

The LRC already has a contract with Harvard Medical School for 100 daysimeters to be used in sleep disorder studies. There will also be a field test completed with the device as part of the Year 2 deliverables of the Daylight Dividends program.

Photosensor/ HVAC Testing at IEC

A study was completed during 10 days in the month of August to measure the effects of daylighting on light and HVAC energy use under different glazing conditions. The glazing conditions used were the conditions used at the IEC for the Cool Daylighting testing. The weather consisted of a range of daytime temperatures and varying sun conditions.

Peter Morante, LRC, stated the findings: In sunny conditions, 65% chance of either HVAC or Lighting dominating energy use. Partly cloudy or cloudy conditions, favor daylight, save more money dimming the lighting, favor clear glass.

Lamp/ Dimming Ballast Update

Conan O'Rourke and Lei Deng, LRC, presented an update of the lamp/ dimming ballast findings and issues, and made a proposal to continue with life testing (with funding from other sources).

Dayswitch & Autoblinds Update

Cy Eaton and Nick Pandya, LRC, presented the progress being made on the dayswitch and autoblinds project, and explained the operation of the dayswitch and autoblind mechanisms. Analysis completed shows the system saves somewhat less energy than a perfect dimming system with materials costs less than 30% of the dimming system.

Year 1 Budget & Expenditures

Peter Morante, LRC, presented the Year 1 budget and expenditures. He estimated each line item has an error of ± $10,000. The Seed Research line item went over budget due to RPI mark-up on the contracts. The first $25,000 of every subcontract is marked up for RPI overheads. The LRC will try to find a way around this markup for the next seed research funding. (note: The LRC has found a method of avoiding the RPI markup for the seed research contracts including Year 1.) The cost of the website was underestimated. However, in total, the project has come in slightly under budget for the year (by about $10,000).

Review of the Year 2 Budget

Roundtables

The contract does not specify what the next set of roundtables might be. A proposal was made to have a roundtable of experts (people doing daylighting, electrical lighting designers, architects, and owners) to see how they are making the market transformation towards daylighting buildings. In whatever form, the purpose of the roundtable would be to provide input to where the holes might be in daylighting. The roundtable would make a compelling case for daylighting. A proposal was made to create a video from the roundtables. The video would address the question, "Why do daylighting".

Biophilia Study of Outdoor View was not approved for Year 2. $20,000 allotted for this study will be transferred to the Lamp/ Dimming Ballast Compatibility Life Test.

Daysimeter field studies were approved for Year 2.

IEC Winter Testing

Winter testing at the Iowa Energy Center was approved. The Iowa Energy Center study will resume in the winter for approximately 10 days using the same conditions as the summer study. A literature review was added to determine if studies have correlated actual data with computer energy modeling (with programs such as DOE2). A computer model validation of the summer data will be completed. Iowa State University may have a DOE2 model of the IEC complete for use.

Dayswitch and autoblind development was approved for Year 2.

Lamp/ Dimming Ballast Compatibility Life Test

$20,000 allotted budget for the biophilia study was added to the $20,000 for lamp/ dimming ballast compatibility life test for a total budget of $40,000. This study will be contingent upon co-funding from other sources. There must be a defined deliverable at the end of Year 3, which must be more than a progress report.

Seed Research Projects

Year 2 will see the completion of the Year 1 seed research project. The Steering Committee approved the awarding of 5 seed research projects in Year 2. Parameters for these research projects have not yet been determined.

Demonstration Projects

Three demonstration sites will be identified and a preliminary examination conducted. The evaluation of the three Year 1 sites will be completed and results published on the website (*.pdf format) and a hard copy. Year 1 sites include a school in North Carolina, and office buildings in Wisconsin and Oregon.

Daylight Symposium

The Steering Committee approved the planning for a national symposium for daylighting. The planning will be completed in Year 2 and implemented in Year 3.

Next Steering Committee Meeting

The next Steering Committee meeting will be held on March 31st and April 1st, 2004 at Lightfair International in Las Vegas, Nevada. A meeting location will be determined.

MEETING NOTES
DAYLIGHT DIVIDENDS
STEERING COMMITTEE MEETING
MARCH 31 & APRIL 1, 2004

The fourth Steering Committee meeting of the Sponsors for the Daylight Dividends research program was held on March 31 and April 1, 2004 in Las Vegas in conjunction with LightFair. Present representing the Sponsors were the following:

John House	Iowa Energy Center (IEC)
Amy Cortese	Northwest Energy Efficiency Alliance (NEEA)
Dona Stankus	North Carolina Daylighting Consortium (NCDC)
Donald Aumann	California Energy Commission (CEC)
Russ Leslie	Lighting Research Center (LRC)
Peter Morante	LRC

Prior to the meeting Peter Morante met with Marsha Walton, New York State Energy Research and Development Authority (NYSERDA), to review material and options that would be discussed at the meeting. Ms. Walton concurred with recommendations made by the LRC regarding seed research funding, workshop agendas and daylighting symposium suggestions.

<u>Daylighting Activities of Sponsors</u>

NEEA

- The Better Bricks program is still conducting many building simulations for the use of daylighting.
- The daylighting labs are expanding in Portland and Eugene, OR (operated by the University of Oregon) and into Boise, ID (operated by the University of Idaho).
- NEEA has started targeting their daylighting outreach efforts to schools and supermarkets.
- Daylighting controls remain an issue. They believe it is necessary to advance the state of these controls.
- Marketing efforts have included the addition of other than energy daylighting benefits such as return on investment, operations and a positive learning climate.

IEC

- Testing for the LRC and the National Association of State Energy Offices daylight projects have been conducted at the energy station.

CEC

- FineLite has developed a direct/indirect light fixture for use in classrooms. These lights have a teacher control to adjust lighting during the use of audio visual equipment.
- With funding from CEC, Watt Stopper is developing a self-commissioning digitally based photosensor.
- SPOT (sensor placement optimization tool) is now available. It is a software package base on radiance that simulates the placement of the photo sensor to optimize its placement. The software resides in the public domain.

- CEC suggest possibly updating the NLPIP Specifier Report on photosensors.

NCDC

- Developing a brochure targeting marketing efforts with school systems for the use of daylight.
- A database of green buildings technologies is being developed. Dona asked if this could be linked to the Daylight Dividends website. Yes it can.
- There is an evaluation of low income school retrofits to daylighting ongoing.
- Design and funding for a North Carolina daylighting design center is ongoing.

LRC

- The LRC presented results of student surveys and interviews at the Smith Middle School. This is the first Daylight Dividends site evaluation. The results are included in Appendix A.
- Data collected during the winter testing at the Iowa Energy Center was also presented. These tests examined lighting and heating energy with the dependant variable being the windows. One set of rooms used a clear glass with visual transmittance of 0.73 and another set of rooms used tinted glass with visual transmittance of 0.23. The results are included in Appendix B.

Site Studies and Evaluations

The Steering Committee directed the LRC to shift away from site studies and cases to demonstrations of technologies. It was suggested demonstrations of photo sensor technologies be explored. The LRC believes the deliverables are broad enough in this area to accommodate technology demonstrations and will pursue this path. It will report back to the Steering Committee on its pursuit. Another possibility might be to develop a design guide by climate area.

The Steering Committee also agreed that only electronic pdf files are required for the current case studies. Paper publications will not be required.

Seed Research

The LRC suggested that the "How to" guide to designing daylit buildings at minimal additional cost replace the Penn State seed research proposal. RPI is having difficulty contracting with Penn State for the top lighting study. Penn State wants changes in the basic contract that RPI has with NYSERDA. The Steering Committee concurred. The LRC will continue to pursue contract negotiations with Penn State for inclusion in the next round of seed research grants. The Steering Committee agreed to waive the co-funding for the "how to" guide project. NYSERDA also concurred with this recommendation.

Suggestions for areas for the next round of seed research request for proposals where discussed. The Steering Committee suggested the following areas which will be included in the next RFP.

- Regional demonstrations of technologies or case studies. (Must ensure objectivity in data collection and reporting)

- Compendium of daylighting solutions employing minor incremental costs such as hardware, control systems, design approaches, lighting fixtures.
- Developing plans for how to develop a daylighting outreach center, plans for how to set up the labs, how to do outreach, how to continue to get funding. (A business/marketing/technology plan for a daylighting design center)
- An open category that encompasses the objectives of the Daylight Dividends program.
- Novel idea development on how to get Daylight Dividends information to practitioners, users (series of articles, bulletin board, class at AIA conference), marketing of daylight
- Use one or more daysimeters provided by the LRC to conduct light and health experiments.
- Control issue research
- Benefits of daylighting

The LRC will be developing the RFP for the next series of seed research to be released in May.

Auto-blinds and Dayswitch
The LRC updated all present on the progress with the auto blind control and the Dayswitch. A peer reviewed article has been written and will appear in *Lighting Research and Technology*. The article is attached as Appendix C.

Lamp/Dimming Ballast Compatibility
With the additional funding from DOE and the lamp and ballast manufacturers, the Steering Committee approved the use of $40,000 that was set aside in the Daylight Dividends budget to assist in the lamp/dimming ballast work.

Daylight Dividends Website
The Steering Committee directed the LRC to explore means of coordinating the Daylight Dividends web site efforts with those proposed by the daylighting group of LightFair. Russ Leslie will follow up on this effort.

Workshop and Symposium
The LRC proposed a symposium that is a daylighting controls institute/workshop. This would be a hands-on workshop where designers/specifiers, etc. can experience how to specify, install, commission daylighting controls. What works and what doesn’t. What performance specifications should be included. The thought is to train the trainers through LRC/Daylight Dividends efforts. A tool kit of controls and other equipment would be assembled as part of the effort. This suggestion comes in response to the barriers that all express with regard to daylighting controls.

The workshop would be used to develop the curriculum for the symposium. Experts would be invited to discuss what should be included in the training. The LRC will put together a “straw person” curriculum as the starting point for discussions. It was suggested that a workshop could be held in conjunction with the Seattle Lighting Lab controls summit. Amy Cortese will explore this possibility. It may be worthwhile to hold a second workshop someplace in the east to ensure balance. The LRC will also develop a budget for the workshop and for developing the curriculum and present it to Steering Committee members for their approval.

The Steering Committee concurred with the LRC's workshop and symposium suggestion. NYSERDA also concurred.

Year Two Metrics

The Steering Committee directed the LRC to develop Year Two metrics based on the deliverables for Year Two. While DOE would like the metrics to include changes in the number of daylit buildings, this metric, if it can be developed, may have no relationship to Daylight Dividends efforts.

Budget

Peter Morante indicated the Year Two budget is tight especially to complete three site case studies that are currently underway. Also, the overhead rates of RPI should apply to the seed research grants. This will increase the cost of these grants by 50%. To relieve some of the budget pressure, the Steering Committee approved replacing the Penn State seed research with the "how to" guide. Also, the auto blind and Dayswitch projects look like they will come in under budget.

The LRC will develop year end budget estimates that include the development of the symposium curriculum and distribute to the Steering Committee.

Future Work

The Steering Committee has directed the LRC to examine means of cooperation between its efforts and those of the LightFair daylighting group.

Also, the LRC is to examine where holes still exist in overcoming barriers to the use of daylighting. Future work should be directed at filling these holes.

Next Steering Committee Meeting

The next Steering Committee meeting will be in the fall. It was suggested that it be held in conjunction with any planned NLPIP meeting. If the LRC is going to have a fall Partners Day, it should be held in conjunction with that event also.

MEETING NOTES
DAYLIGHT DIVIDENDS
STEERING COMMITTEE MEETING
October 28 & 29, 2004

Present:

Joel Loveland, NEEA	Charles Fay, NYSERDA
John House, IEC	Sam Fankhauser, CL&P
Russ Leslie, LRC	Joel Chaddock, DOE
Karl Johnson, Consultant to CEC	Don Aumann, CEC
Dona Stankus, NCDC	Peter Morante, LRC
Guests: Conan O'Rourke, LRC	Terry Klein, LRC
Mark Rea, LRC	

Sponsor Updates:

NYSERDA: The New York Times building mockup has been completed and the New York Times is selecting equipment manufacturers based on the mockup results. Dimming ballasts, lighting controls and shades have all been selected. Discussions centered on the possibility of the building using the LRC developed LED elevator fixtures. Charles is to check to see if there is any interest.

NCDC: Curriculum development for professional building designers is underway to encourage additional use of daylighting. There are many school buildings being designed to take advantage of daylighting.

CL&P: There are no new dollars for research development and demonstration projects within the 2004 or 2005 CL&P conservation budget. Daylight Dividends is one of only two projects that continue to get funding.

LRC: Peter distributed two draft case studies for TomoTherapy and Harmony Library. Peter asked that comments on the Harmony Library be passed on to him by November 15, 2004. A final draft of the TomoTherapy site will be sent to the Steering Committee for comment later in November.

The LRC has been asked to participate in the Daylighting Institute of LightFair with presentation on daylighting controls and daylighting and health.

NEEA: There are major changes in staffing at NEEA. Amy Cortese and Dave Hewitt have left. Dave's position will be advertised soon.

There are now five daylighting labs in the Pacific Northwest, Seattle, Portland, Boise, Spokane and Bowsman, MT.

Joel indicated there is a working group developing some definitions and metrics regarding daylighting, sun control and energy efficiency.

There are 22 schools and a total of 70 projects underway in the Pacific Northwest that will utilize daylighting. Albertson Supermarkets has elected to use daylighting in there new stores.

CEC: The Watt Stopper has delayed introduction of their self commissioning photosensor until spring 2005.

A new software program to assist in the selection and placement of photosensors has been released in its beta version. The Sensor Placement and Orientation Tool (SPOT) is available for testing.

CEC is setting aside research grants to develop emerging technologies.

With regret, we must say goodbye to Don Aumann as the CEC representative to Daylight Dividends. Don is moving on to the California Lighting Technology Center.

IEC: Testing of internal and external shading devices is underway at the Iowa Energy Resource Station.

Project Updates

Lamp/Dimming Ballast Compatibility

Conan O’Rourke updated the group on the work started under the Daylight Dividends program and continued through a grant from DOE and in kind services from lamp and ballast manufacturers. We were able to leverage the Daylight Dividend work to receive at $275,000 DOE grant and $228,000 of in kind services from lamp and ballast manufacturers. The goal is to develop a metric for ballast manufacturers that will lead to the compromise of lamp life in dimming situations. Four ballast and three lamp manufacturers are participating. Lamp life testing will commence shortly.

Daylighting Control Simulator

Terry Klein demonstrated the use of the simulator to examine different ballast and photosensor operations. Each sponsor will receive a simulator at no additional cost. The Steering Committee questioned how many different ballasts on photosensors will be provided with the simulator. They suggested a good conversation with manufacturers might help in determining the number of ballasts and sensors to include.

Iowa Study

A discussion of the results of the collection of energy data at the Iowa Energy Resource Station occurred. The LRC was directed to contract with an organization to conduct

DOE-2 simulations of the ERS data to determine if building simulations can match closely actual data. Multiple simulations will be conducted.

- Given actual weather and building data, simulate electric, heating and cooling energy use.
- Given actual weather and electric use data, simulate heating and cooling energy use.

The question to be answered is, does DOE-2 provide accurate estimates of daylighting savings.

2004 Program Progress Report and Budget

Peter presented a review of the 2004 progress against the proposed program and the budget expenditures. These documents are attached at the end of this report.

All proposed projects and assignments will be completed by the end of 2004. It was suggested the LRC write a short article summarizing the three case studies for publication in designers and building owners periodicals. The LRC will undertake this task.

The 2004 budget and expenditures are in line. Administrative costs are lower than expected as are the development of the Dayswitch and the blind control. Field studies of the daysimeter are also coming in less than anticipated. These dollars are being used to develop the Daylight Controls Practicum and simulator.

2005 Program and Budget

The LRC presented a straw person program and budget for Year 3 of Daylight Dividends. This document is attached to this report. There was lots of discussion regarding the program. The Steering Committee wants to see additional market/technical transfer occur than was planned in the straw person program. Information transfer suggestions included:

- Linking to regional and local organizations that have strong links with the design community.
- Tie into national meeting of AIA, BOMA, IFMA, American Society of School Administrators, etc.
- Look at possible links to LEED.
- Publication of a book/booklet with all the daylighting papers, journal, magazine articles.
- Write a newsletter to daylight practitioners.
- Conduct a forum for daylight practitioners to bring researchers, policy makers, program administrators, designers together to share information. Discuss what has to be done to move daylighting into the main stream.
- Write articles for trade journals beyond the lighting community.
- Publish news releases.
- Improve visibility of web site.

The LRC will develop a draft outreach plan to the Steering Committee for comment. This plan will include a budget.

It was discussed and agreed to demonstrate and evaluate the Dayswitch and the mechanical blind (G. Z. Brown's) technologies at actual sites as long as manufacturing partners can be found. Both energy and human factor evaluations will be undertaken. The LRC will develop the proposed demonstrations with CL&P for the Dayswitch and with G. Z. Brown for the shade control and report back to the Steering Committee on specific demonstrations by the end of 2004. It was further agreed to support the updating of the photosensor product testing under the NLPIP program. Daylight Dividends will incur 50% of the cost and NLPIP will pay the rest.

Daylight Dividends beyond Year 3

There appeared to be interest to continue Daylight Dividends beyond the current end date of 12-31-05. Steering Committee members present indicated a desire to continue market/technology/information transfer activities and to examine those areas still needing research. The areas of interest for a program beyond Year 3 are:

- Outreach
- Developing more pieces of evidence that daylighting is good beyond just energy savings. (metrics)
- More case studies.
- Epidemiology areas of research
- Updating websites and training materials.

The LRC will put together a plan that addresses the needs of the sponsors and present it by the next Steering Committee meeting.

The Daylighting Forum and Daylight Dividends

It was agreed the LRC will open dialog with Abby Vogen and Jeff Johnson on organizational issues for the Daylighting Forum now scheduled to take place on Sunday of LightFair. It was suggested a meeting of all parties take place soon to discuss what we can do together to make daylighting more viable. The Daylight Dividends Steering Committee would like to see a full day of discussions occur at LightFair on the Saturday prior to the Daylighting Institute where research, education, policy, programs and design issues are discussed. Peter and Russ will set up a meeting.

Seed Research Update

The five original seed research projects were discussed. The Guide to Daylighting Schools is completed. The development of the manual shade controller is in the lab testing phase. The simulations of toplighting strategies are being conducted. The value of a view report is in its draft stages. The only seed research for which there is no data available is overcoming barriers to daylighting in schools. This work is to be completed by Dr. Eckerlin at North Carolina State University.

The Steering Committee requested the LRC to contact Dr. Eckerlin, in writing, and give him the option of extending the deadline for the completion of his work or to transfer the work to another source.

Four seed research projects were selected for funding for the second round of seed research funding. These projects include the development of a template for the creation of daylighting labs, potential energy savings from side lighting strategies, the relationship between a view and employee sick days and a software program.

Other Business

Discussion of the Peter Boyce review of the Heshong-Mahone recent study on student learning was undertaken by the Steering Committee at the request of Russ. Russ moved that the LRC first e-mail Lisa Heshong the Boyce review again and then contact (must talk personally) Lisa to discuss Boyce’s findings. The LRC will offer Lisa the opportunity to comment on these findings and to have her comments published along with the review on the Daylight Dividends web site. The motion was seconded by Sam and motioned carried.

The LRC will contact Lisa.

MEETING NOTES
DAYLIGHT DIVIDENDS STEERING COMMITTEE MEETING
May 11 & 12, 2005
Rosslyn, Virginia

Steering Committee Members Present

Both days:
Curt Klaassen, IEC
Dona Stankus, NCDC
Russ Leslie, LRC
Sam Fankhauser, CL&P
Joel Loveland, NEEA

May 12 only:
Marsha Walton, NYSERDA
Karl Johnson, CEC
Eric Stubee (via phone), CEC

May 11 only:
Joel Chaddock, DOE

Others present from sponsoring organizations:
Peter Morante, LRC
James Brodrick, DOE

Guests:
Ron Runkles, NEMA
Dave Peterson, NEMA’s Committee on Lighting Controls

Current Daylighting Activities Ongoing at Each Member Organization.

North Carolina Daylighting Consortium:
The NCDC has received a small grant to conduct a high performance building workshop on June 17. This workshop will emphasize daylighting. Part of the workshop will include a modified version of the Daylighting Controls developed for Daylight Dividends.

Current emphasis in daylighting is with primary and secondary schools.

Connecticut Light and Power:
CL&P is starting to emphasize daylighting in its new commercial construction energy conservation program. They are providing information on a project by project basis.

The availability of R&D funding still exists for very specific cases including continuations of existing projects.

Lighting Research Center:
With a pending grant from NYSTAR, the LRC is going to begin a Lighting Technology Greenhouse program for the development and commercialization of innovative lighting products. This is to help smaller lighting manufacturers commercialize new products.

A series of roundtables are planned to help develop labeling on packages that will help consumers delineate between lamp color temperatures.

The LRC, led by Dr. Narendran, has developed a lens for LEDs called a scatter photon extractor that has the ability to increase light output from LEDs by 50%.

A grant from NYSERDA will allow the LRC to further develop the DaySwitch, conceptually developed with Daylight Dividends funding, and to conduct a full scale demonstration and evaluation of the product.

Department of Energy:
Ongoing research into the development and use of lighting controls has an emphasis within DOE.

Northwest Energy Efficiency Alliance:
Funding cycle renewal for the Alliance is currently being done. This cycle is to fund the Alliance for another three years.

Changes in management within the Alliance have taken place. Jeff Cole is replacing Amy Cortese in the commercial lighting area. Skip Schick has replaced Dave Hewitt as manager of the commercial programs.

The lighting labs are taking on additional responsibilities and will be examining whole building energy integration as part of their design assistance. This will include a broader education outreach.

The Alliance has identified ownership clusters it will be placing emphasis on as part of its outreach efforts. These clusters include hospitals, regional retail stores and real estate investment trusts.

The State of Washington has made sustainable schools a priority. These schools will include daylighting. They have also indicated all state owned buildings greater than 5,000 square feet will be LEED silver certified.

Iowa Energy Center:
IEC will conduct the Daylighting Controls Practicum this fall.

National Electric Manufacturers Association:
NEMA was asked to express their interest in daylighting. NEMA’s premise is the industry needs proven tools to effectively assess daylight harvesting and to measure energy conservation. NEMA Standard 243 has set a standard for the DALI lighting control devices and a system to verify products work according to this standard. Building designers also need information on daylighting performance, how much light does one get from different types of fenestration systems.

Budget Review

Peter Morante conducted a budget review of all years and all activities undertaken by Daylight Dividends. The program will be within 1% of the original budget set four years ago. All activities will be completed. The addition of the Daylighting Controls Practicum caused the demonstration projects for the shade controller and the DaySwitch to be reduced in scope. These demos will still achieve their goals.

A copy of the budget analysis is attached as a separate file to the e-mail.

Review of the DaySwitch Technology

The DaySwitch was conceptually conceived and an economic analysis was completed using Daylight Dividend funding. A grant from CEC's Energy Innovation Small Grant program was secured by the LRC to develop a prototype DaySwitch. The DaySwitch turns electric lights on or off based on the amount of daylight present in the space. It is a low cost ($7 in component costs), easy to install (less than 10 minutes) and calibrate (less than two minutes) alternative to daylight dimming systems. The Day Switch is installed on individual lighting fixtures. Next steps include conducting a laboratory demonstration at both the LRC and the University of Oregon as part of the Daylight Dividends program.

The photo below is of the DaySwitch prototype.

Results of the Circadian/Daylighting/Productivity Study

The results of experiments into increases in productivity due to circadian light were presented. A summary of the results are:

- The Daysimeter developed with funding from Daylight Dividends worked well in measuring the amounts of photopic and circadian light entering the subjects' eyes.

- Those subjects exposed to light with high circadian response spectrum performed better than those where this spectrum was filtered from entering the eye.
- The results of this study offer some support for the inference that stimulation of the circadian system by daylight positively affects performance.
- However, additional testing is required before claims can be made with certainty.

The full report is attached to the distribution e-mail.

Daylight Dividends Program Extension

The current funding for Daylight Dividends ends on December 31, 2005. All sponsor representatives indicated a strong desire to continue the program beyond its current ending date. The LRC will lead an effort to develop a consortium of sponsors, beginning with current sponsors, to fund future daylighting work and to file a proposal for matching funds with STAC. Sponsor representatives were asked to discuss continued funding with their organizations. Letters of commitment will be required for the STAC proposal by mid-June.

A straw person set of activities/tasks was presented as a discussion starting point for activities beyond this year. It was proposed to extend efforts for another three years at budget levels similar to the initial funding. A copy of the straw person activities is attached to the distribution e-mail.

Comments on the straw person draft:

- More of a general outreach would be appreciated. Conduct meetings at each sponsor location for building owners and designers.
- A high priority issue is the establishment of metrics for what is good daylighting. This effort is in progress and will be addressed by the Daylighting forum.
- The plan needs to contain more specific action items so it can be reviewed by each sponsor for continued funding.
- A need to train national accounts (retail, hospitality, supermarkets) on daylighting – both their facility managers and their building designers.
- Provide direct design assistance to national accounts on specific buildings being designed.
- Education and outreach priority.
- Priority on technology understanding, testing, demonstration and outreach and on the effects of daylighting on human behavior.
- More specifics on media outreach.
- Continue the editorial board to review compendium of daylighting research. We need critical reviews.
- Daylight Dividends should concentrate in areas that are filling the gaps, i.e. technology development and evaluation, human factors research and serving as an objective reviewer for conflicting claims.
- Reduced emphasis should be put on additional focus groups.

Review of Proposed Demonstration Projects

Daylight Dividends will undertake the demonstration and evaluation of two emerging technologies, the DaySwitch and a mechanical shade control device developed under a seed research grant from Daylight Dividends. Two demo sites will be chosen, one at the LRC or nearby and one at the University of Oregon. Each site will have two DaySwitches and shade controllers installed. The University of Oregon and the LRC will jointly develop the evaluation criteria for both energy use and for occupant acceptance. They will also jointly publish a report on their findings.

Daylighting Forum at LightFair Discussion

Joel Loveland and Russ Leslie attended the Daylighting Forum as representatives of Daylight Dividends. The outcome of this forum is to conduct a meeting in the fall where the primary topic will be the development of a set of metrics for what is good daylighting.

Capturing the Daylight Dividends
Steering Committee Meeting
January 11 & 12, 2006

January 11, 2006

Present: Joel Chaddock, USDOE; Joel Loveland, NEEA; Dona Stankus, NCDLC;
Russ Leslie and Peter Morante, LRC
Via Phone: Michael Seaman, CEC; Marsha Walton and Peter Douglas, NYSERDA
Guests: Jon Zubizarreta, Innovative Design; Dale Brentrup, UNC-Charlette; Alicia Ravetto, Alicia Ravetto Architects; Gabe Arnold, Efficiency Vermont

This day was set aside to present the final report and accomplishments of the three year Daylight Dividends efforts to U.S. Department of Energy and to conduct a “post-mortem” on the program (what we did correctly and what we would change in the future).

Peter Morante presented the results of the three year Daylight Dividends project to the group. The presentation is attached to these meeting notes. The review included program objectives and relevance (why do daylighting), identification of barriers and current research needs, setting of the research agenda, outcomes of the research conducted for the project, seed research studies, demonstrations of technologies and case studies, education and outreach efforts.

A post-mortem was conducted after the presentation of the final report. The Steering Committee wanted to understand what we did well and where improvements could be made on future collaborative project. The following are observations made by Steering Committee members.

- A collaboration of all the parties involved in Daylight Dividends allowed for sharing of information, selecting projects that provided information not otherwise available to a wide audience of daylighting practitioners.
- Project management was excellent.
- There were deliverables within the project, like the Daylighting Controls Practicum, that could only have been accomplished through a collaborative effort.
- Case studies help educate building designers and owners on the benefits of daylighting as well as what technologies an approaches work best.
- The contractual differences of the sponsors in funding a collaborative project were handled by the LRC or NYSERDA to meet the needs of the individual funding organizations. It allowed for flexibility in choosing project.
- The LRC is extremely capable in conduct technical research.
- Evaluating existing building systems creates a knowledge base for designers.
- There are a number of researchers, building designers and product manufacturers all doing work in the daylighting arena. However, they do not communicate well together and Daylight Dividends could act as a catalyst to bring parties together. Look at the old International Daylighting Conference and possibly a “Daylighting” Journal as means of providing communications.
- Daylight Dividends research needs to reach a larger audience. It needs to put its results into formats that are more usable to building designers and owners. Brochures, articles, green buildings approach.
- Disseminating the information and research already conducted through Daylight Dividends should play a key role going forward.
- Means of getting architects and consulting engineers to change design practices is needed and has been missing from the Daylight Dividends program.

January 12, 2006

Present: Joel Loveland, NEEA; Dona Stankus, NCDLC; Russ Leslie and Peter Morante, LRC; Gabe Arnold, Efficiency Vermont
Via Phone: Michael Seaman, CEC; Marsha Walton, NYSERDA
Guests: Mike Nicklas, Innovative Design; Dale Brentrup, UNC-Charlette; Alicia Ravetto, Alicia Ravetto Architects

January 12 was used to talk about the future of Daylight Dividends. Was there enough interest and work to be completed to continue to work in collaboration even without DOE funding?

Each sponsor presented current daylighting activities within their regional/state areas.

NYSERDA – Their new construction program includes incentives for building owners to utilize daylight. It also includes design assistance. Ten buildings have availed themselves of the design assistance. However, only two building have been built using daylighting.

The New York Times building daylighting efforts continue. The design is complete.

NYSERDA is sponsoring continued research for the development and commercialization of the DaySwitch and a load shed ballast.

The Daylighting Controls Practicum is being offered at six sites around New York state. One thing that seems to be missing from the curriculum is simple cost/benefit analyses.

A Program Opportunity Notice (PON) will be issued shortly explicitly for daylighting. This PON is to offer design assistance, training, case studies etc. for daylighting buildings.

North Carolina Daylighting Consortium - A daylighting workshop conducted in June 2005 included portions of the Daylighting Controls Practicum.

The only funding available for daylighting work within North Carolina is to continue to maintain the daylighting website. Guests present will assist in attempting to find funding to continue membership in Daylight Dividends.

Efficiency Vermont – Building Designers believe in the green building concept but seem to be having issues accepting/using daylighting. Daylighting is still being treated as an add-on rather than designing the building to use daylighting from the start.

The annual workshop for building designers will include daylighting.

NEEA – The Daylighting Labs in the Pacific Northwest are being renamed and redirected to be Integrated Building Design Labs. Consultants within the labs will provide guidance in daylighting, HVAC systems and building envelope.

It has taken two to three years of constantly working with building designers before they catch on how to design for effective daylighting and for them to accept daylighting in buildings.
The Integrated Building Design Labs use E-Quest modeling software in the early stages of a building's design. The SPOT (sensor placement optimization toll) software package is being updated to interface with DaySIM software.

NEEA is about to place many case studies of completed daylighting projects on its website.

CEC – Metrics for skylights, tubular devices and other toplighting strategies are needed within California. The latest Title 24 has a requirement for the use of toplighting in single story buildings over 20,000 square feet. Its imperative that good toplighting strategies be employed.

LRC – Through its NLPIP program, the LRC is seeking sites where there are issues with lighting controls and daylighting systems. NLPIP is preparing a series of diagnostic reports on the issues encountered in the field and resolutions to the problems. The Daylight Dividends sponsors identified a few sites where issues exist and they would like the LRC to perform some diagnostic testing.

Guest Comments – UNC, Charlotte is training design professionals in daylighting use. They have also put daylighting controls in the university libarary with minimal success. The university has abandoned their effort to make these controls work properly. It has been a maintenance nightmare. They are doing a project with the Bank of America on a branch bank.

Mike Nicklas **–** There are problems in daylighting and energy connection being well understood. More design tools would help. The PC version of Radiance is inaccurate and DOE 2 has been dumb down to make it easier to use. Mike asked the group if measures and metrics need to be done by climate. Note: no answer was recorded.

Appendix B: Budget Review

Revenues	**Year One**	**Year Two**	**Year Three**	**Total**
U.S. DOE	$300,000	$300,000	$250,000	$850,000
NYSERDA	$116,318	$116,318	$116,318	$348,954
CEC	$50,000	$50,000	$50,000	$150,000
CL&P	$50,000	$50,000	$50,000	$150,000
IEC	$25,000	$25,000	$25,000	$75,000
NEEA	$50,000	$50,000	$50,000	$150,000
NCDC		$10,000	$5,000	$15,000
	$591,318	$601,318	$546,318	$1,738,954

Allocations/Expenditures

	Allocation	Expense	Allocation	Expense	Allocation	Expense	Allocation	Expense
Task 1: Program Ops/ Priority Setting	$262,518	$250,132	$106,318	$136,384	$86,318	$73,293	$455,154	$459,809
Task 2: Conduct RD&D Activities	$186,500	$171,700	$188,000	$204,414	$85,000	$100,148	$459,500	$476,262
Task 3: Seed Research	$40,000	$62,000	$90,000	$21,960	$190,300	$215,560	$320,300	$299,520
Task 4: National, State Daylight Activity	$20,000	$17,000	$10,000	$0	$0	$0	$30,000	$17,000
Task 5: Demonstration Projects	$30,000	$19,400	$137,000	$99,613	$129,015	$98,325	$296,015	$217,338
Task 6: Dissemination, Education, Outreach	$52,300	$89,000	$70,000	$162,887	$55,685	$41,111	$177,985	$292,998
Total	**$591,318**	**$609,232**	**$601,318**	**$625,258**	**$546,318**	**$528,437**	**$1,738,954**	**$1,762,927**

Appendix C: Possible Influence by the Circadian System on Human Performance

(begins on following page)

Capturing the Daylight Dividend:

Possible Influence by the Circadian System on Human Performance

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Submitted to:	**California Energy Commission** **Connecticut Light & Power** **Iowa Energy Center** **Lighting Research Center** **North Carolina Daylighting Consortium** **Northwest Energy Efficiency Alliance** **New York State Energy Research and Development Authority** **U.S. Department of Energy**
Prepared by:	**Lighting Research Center**
Team Leaders:	**Mariana Figueiro** **Mark Rea**
Project Team:	**Andrew Bierman, Jennifer Brons, Spencer Flagg, Terry Klein**
Date:	**May 2, 2005**

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Background

It is well known that people like daylight in their work environment (Hopkinson and Kay, 1969; Cuttle, 1983; Boyce, 2003; Leslie, 2000). It has been argued recently that daylight also positively affects performance (Heschong et al., 1999; Heschong et al., 2003a; Heschong et al., 2003b), but a cause-and-effect mechanism relating daylight to good performance has never been shown. Certainly daylight is not a special light source for vision, and the link between improved psychological well-being and improved performance cannot be shown reliably (Boyce and Rea, 2001; Boyce et al., 2003). Another line of research has emerged in the last 20 years potentially providing a physiological foundation for the widely accepted but, again, undocumented belief that daylight improves productivity (Leslie, 2000).

Basic research in circadian photobiology (Turek and Zee, 1999; Arendt, 1995; Moore, 1997; Klein, 1993) suggests that light plays a very important role in regulating the circadian (approximately 24-hour) patterns of human behavior by directly affecting the internal timing mechanisms of the body (Jewett et al., 1997; Turek and Zee, 1999; van Someren et al., 1997; Lewy et al., 1982). In contrast to the visual system, however, the circadian system requires higher light levels (McIntyre et al., 1989) and shorter wavelength (blue) light to be activated (Brainard et al., 2001; Thapan et al., 2001). Since humans evolved under daylight (and darkness), it is conceivable that the physical characteristics of daylight (quantity, spectrum, distribution, timing and duration) might be fundamentally important to the regulation of human performance through the circadian system (Rea et al., 2002). Moreover, since light plays an important role in regulating human behavior through this circadian clock, daylight acting on the circadian system could conceivably positively affect performance. Current electric lighting is manufactured, designed and specified only to meet visual requirements, so daylight in buildings may indeed provide a special light source for driving and regulating human circadian behavior because it is dominated by short-wavelength radiation and can provide high light levels.

The rapidly evolving understanding of the circadian system led us to speculate that people working in interior offices illuminated with fluorescent lighting systems that are optimized for the visual system may not be exposed to lighting conditions sufficient to activate the circadian system (Stevens and Rea, 2001). In particular, we speculated that "circadian darkness" in interior offices may negatively affect performance because electric lighting (at light levels typically found in indoor environments) does not provide sufficient illumination to stimulate and synchronize the circadian clock to the day-night cycle (Figueiro et al., 2002). Perhaps then, the strong preferences by office workers for daylighted spaces may have a foundation in the circadian system. In order to directly test the hypothesis that the circadian system might be an underlying biophysical mechanism affecting human behavior, it was necessary to control and estimate blue light exposure to subjects while measuring their performance. As mentioned above, the circadian system is maximally sensitive to blue light (Brainard et al., 2001; Thapan et al., 2001). It was hypothesized that the absence of blue light during the experiment, characterized by the "Daysimeter" measurements, would adversely impact subject performance.

Methods

An experiment was designed to contrast performance for four independent sub-groups of subjects in a windowed space. Two groups of twelve undergraduate student subjects (n = 24) were separately recruited from different local universities for the experiment; Group 1 data were collected on a Saturday in October 2005 and those from Group 2 were obtained on a Sunday later that month. All subjects ranged in age from 19 to 26 years; all had normal acuity and color vision as determined immediately prior to testing. All subjects were paid the same base-pay of $15/h, but two bonus schemes were employed. Everyone in Group 1 (n = 12) received a $12.50 bonus for completing the experiment; thus, the total bonus payment for all subjects in Group 1 was $150.00 ($12.50 x 12). The subjects in Group 2 (n = 12) also received a total of $150 in bonus payments for completing the experiment, but these subjects received a graduated bonus payment based upon performance measured by the number of presentations completed. The top three performing subjects received a $20 bonus, the next three top performers received a $15 bonus, the next three received a $10 bonus, and the three poorest performers received $5 bonus.

Within both groups of subjects, half wore orange glasses giving them limited blue light exposure during the experiment and the other half wore clear glasses providing normal, unattenuated light exposure to daylight from a north sky. It was hypothesized that subjects with clear safety glasses should (a) perform better, and (b) take shorter breaks than those with orange safety glasses because the circadian systems of subjects with orange glasses would be much less stimulated by the available light. It was also hypothesized that font size would affect performance such that the smaller the font size, the poorer the level of performance. Finally, it was expected that subjects in Group 1 would perform worse than subjects in Group 2 due to the difference in performance-based bonus payments.

Measurements from a newly developed photometric device, termed the "Daysimeter," characterized retinal light exposures for the orange glasses and clear glasses sub-groups. These measurements were obtained in February 2005. The Daysimeter is worn on the head and is equipped with two light sensitive detectors positioned approximately at the plane of the cornea (Figure 1).

Figure 1: Subject wearing the unfiltered Daysimeter, accompanied by the orange filter on the monitor.

One detector is calibrated in terms of conventional photopic illuminance while the other is calibrated to detect blue light, providing a measure of the circadian stimulus to humans (Figure 2). Figures 3a and 3b show measurement data from the Daysimeter during a five-hour session similar to that experienced by the subjects in the actual experiment. Both the photopic and blue light exposures are shown, with and without orange filters placed over the detectors. These filters had a spectral transmission identical to that of the orange glasses worn by the subjects during the experiment.

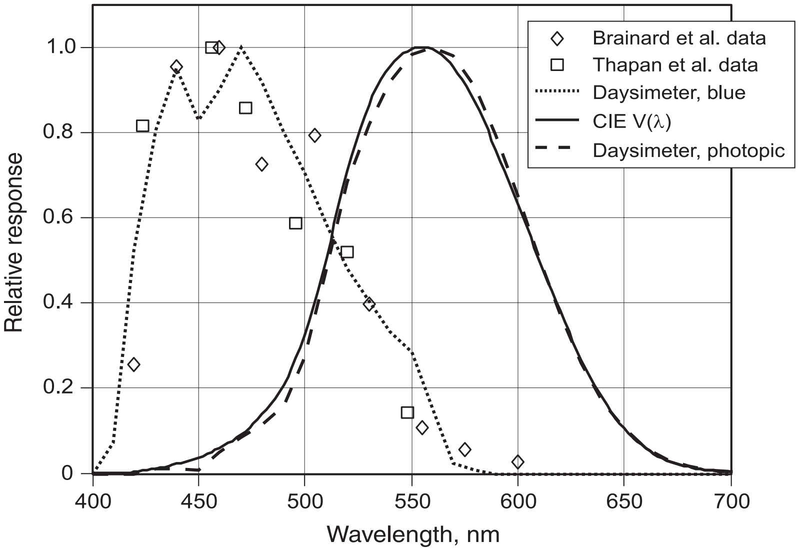
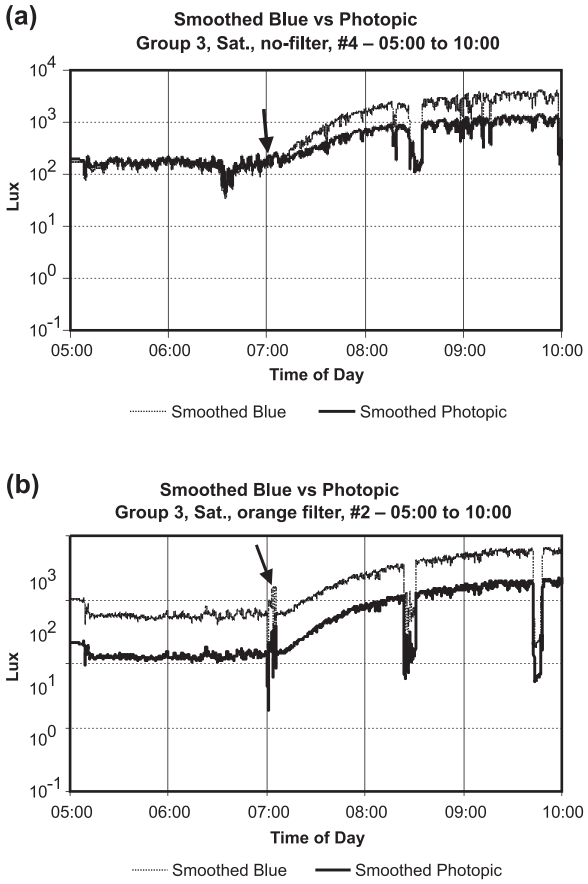


Figure 2: Spectral response of the two sensors of the Daysimeter (photopic [dashed line] and blue [dotted line]), CIE photopic luminous efficiency function (solid line), and data obtained by Brainard et al. (2001) (diamonds), and Thapan et al. (2001) (squares).



Figures 3a and b: Raw data from the two channels of an unfiltered Daysimeter worn by one subject (upper figure) and raw data from the two channels of a filtered Daysimeter worn by one subject (lower subject) during a five-hour experimental session on February 5, 2005. There is a general rise in available light after sunrise (07:03, indicated by the arrow); sharp drops in light level correspond to voluntary breaks taken by the subject in an area adjacent to the experimental space.

Table 1

ORANGE FILTER

Photopic	Blue
929 lux hours	275 blue-lux hours
184.04 average lux (5 h)	54.97 average blue lux (5 h)

NO FILTER

Photopic	Blue
2,247.2 lux hours	5,199 blue-lux hours
449.4 average lux (5 h)	1,039.8 average blue lux (5 h)

Estimated average photopic and blue light levels recorded from four Daysimeters. Four subjects wore a Daysimeter from 05:00 to 10:00 February 5, 2005; four different subjects wore them from 05:00 to 10:00 the following day. Sunrise was 07:04 and 07:03, respectively. One Daysimeter with an orange filter did not record the data properly and those data were not used in the data analyses. Each cell in the table for “orange filter” represents the average of two readings. Each cell in the table for “no filter” represents the average of four readings.

The values in Table 1 show that the blue light exposure for those subjects with clear safety glasses was approximately 18.9 times more than those subjects wearing orange safety glasses but was only 2.4 times greater for the foveal cones (i.e., photopic sensitivity). These data imply that circadian activation would be significantly greater for those subjects wearing clear safety glasses than those wearing the orange safety glasses in the October 2004 experiment.

All other environmental conditions, including the visual stimuli and the view provided by a window, were the same for all subjects. All subjects were seated facing a north-sky window in front of personal computer (PC) screens. Subjects wearing clear glasses viewed the visual task though an orange filter attached to the PC screen. Subject with the orange glasses did not have an orange filter attached to the PC screen (Figure 4).

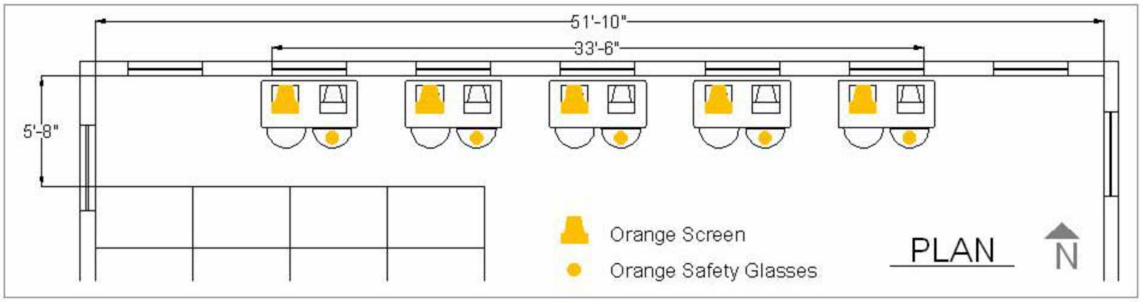


Figure 4: Plan of experimental area, with north-facing windows and twelve workstations. Orange filters were mounted either on the computer monitor or on the subjects' glasses.

A numerical verification task (NVT) (Rea and Ouellette, 1981) was used as the visual stimulus. The numerals were displayed on the PC screen in one of five different font sizes (6, 8, 10, 12 and 14 point), randomly generated by the PC.

All subjects arrived at the laboratory before dawn to minimize light exposure outside the laboratory conditions, and worked for five hours on the NVT presentations. Subjects were allowed to take breaks at any time they wished and to eat non-caffeinated food and drinks provided to them by the experimenters during those breaks.

Results

One dependent variable used to characterize performance, total time to complete each presentation, was subjected to a mixed-factor analysis of variance (ANOVA); groups (1 and 2) and glasses type (orange and clear) were treated as a between-subjects independent variables, while font size (6, 8, 10, 12, and 14-point) was treated as a within-subjects independent variable. The other two dependent variables, correct presentations and total presented, were subjected to a between-subjects ANOVA; groups (1 and 2) and glasses type (orange and clear) were independent variables. The main findings of the laboratory study were:

- Performance, in terms of shorter time to complete each presentation, increased significantly with font size (Figure 5)

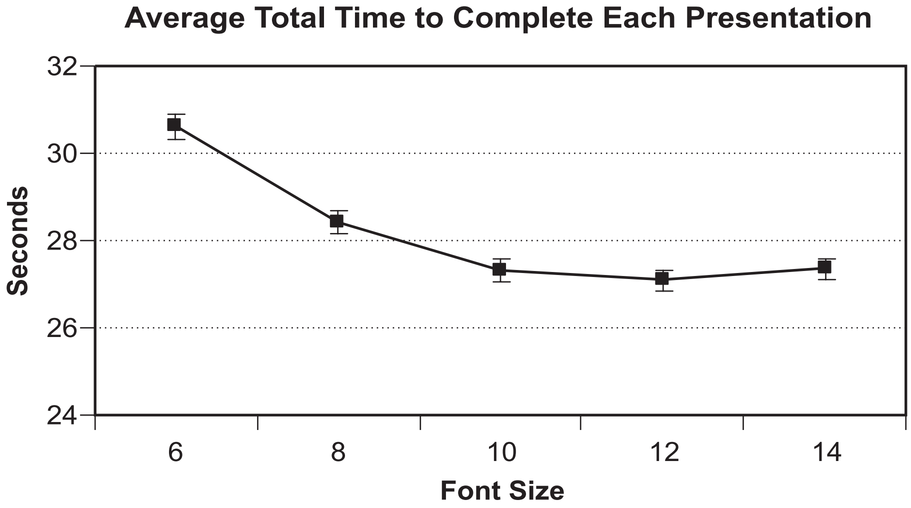


Figure 5: The effect of font size on the average total time (± S.E.M) to complete one presentation of the NVT. Two columns of ten, 7-digit strings were compared for each presentation. Subjects indicated discrepancies, varying from 0 to 3 per presentation, until all discrepancies had been indicated and no false positives had been committed.

- Performance, in terms of shorter time to complete each presentation, was significantly worse for those subjects with limited blue light exposure (orange glasses) than for those subjects with unattenuated daylight exposure (clear glasses). A statistically significant interaction was found between the two types of glasses and the two groups of subjects (Figure 6).
- Due to low statistical power, performance in terms of correct presentations completed and total presented was not statistically significant for either of the independent variables (groups and glasses type).
- Although not statistically significant, subjects with limited blue light exposure (orange glasses) took longer breaks than those with unattenuated daylight exposure.

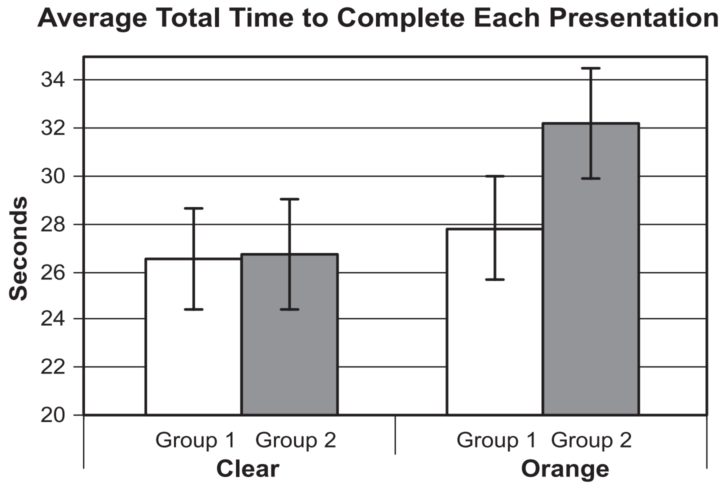


Figure 6: Group-by-glasses type interaction (average ± S.E.M.). In the clear safety glasses conditions, both groups took similar total time to complete each presentation, while when wearing the orange safety glasses, subjects in Group 1 had a shorter total time to complete each presentation than those in Group 2.

Conclusions

The results of this study offer some support for the inference that stimulation of the circadian system by normal daylight positively affects performance. Minimizing retinal exposure to blue light from daylight significantly reduced the speed with which subjects performed the presentations and increased the duration of breaks that subjects took during the experimental sessions, although the latter effect was not significant due to low statistical power in performing the ANOVAs. This study may also suggest that blue light from daylight serves as positive “refreshment,” keeping performance levels high without the need for long break times. When the stimulus to the circadian system is absent (i.e., no exposure to blue light), however, performance decreases and longer breaks are needed, presumably to avoid even greater decrements in performance. Although four independent groups of subjects participated in the study, it must be emphasized that between-subjects designs can be potentially misleading due to inherent differences between the capabilities of the groups (Rea, 1987). Thus, before firm conclusions can be drawn from this study, it is necessary to replicate the study, ideally using a within-subjects design.

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Daylight
Dividends

Appendix D: Impact of Dimming on Lamp Life

(begins on following page)

Rensselaer

The Impact of Dimming on Lamp Life

An Investigation for Daylight Harvesting Applications

Final Project Report

I. Project Sponsor:	U.S. Department of Energy Capturing the Daylight Dividends
II. Date of Report:	January 9, 2004
III. Prepared by:	Lighting Research Center Rensselaer Polytechnic Institute
IV. Project Team:	Conan O'Rourke Andrew Bierman Lei Deng

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I. Introduction

Dimming fluorescent systems have garnered much attention in recent years as a result of the growing popularity of daylight harvesting. These systems have been used as one method to reduce energy consumption from electric lighting when daylight is available in a space. Despite the potential for energy savings, dimming systems have not been prevalent, holding only 1% of sales of electronic ballasts (U.S. Census Bureau 2003). One reason for lackluster sales has been the higher cost of dimming systems, but the resounding issue has been overall system performance. Anecdotal evidence suggests that these systems are either too difficult to install and commission, do not work well in many applications, and cause premature lamp failure.

There are a variety of factors that could impact system performance. Central to the issue of performance is that lamps were not designed to be dimmed. Standards have not been developed in the United States that layout how a lamp should be operated in the dimmed mode in order to maintain proper lamp life. Lamp and ballast manufacturers have been investigating dimming operation and have developed systems that do dim; however, lamp life is still a potential issue.

To address these concerns, the Lighting Research Center (LRC) performed an initial short-term analysis of dimming systems currently available on the market. The LRC also investigated possible methods to evaluate fluorescent system performance while the lamps were operating in a dimmed mode. This report details the results of this investigation.

II. Background – Literature Review Summary

1. Fluorescent lamp anatomy

Fluorescent lamps contain two identical electrodes, one at each end of the tube that act as an anode and a cathode. The electrodes (also known as a filament) provide power to the discharge column, with the electrode acting as a cathode providing the electron current to the discharge column and the electrode acting as an anode removing the electrons. There are compromises in electrode design for starting and operating a lamp as a result of this dual function (Waymouth 1971).

Electrodes are composed of a base metal, tungsten, which supports and heats an emissive coating added to the electrodes. The size and shape of the base metal is different for lamps of different designs. The emissive coating is made from barium (BaO), calcium (CaO), and strontium (SrO_2) oxides and has a very low work function, ranging from 0.9 to 1.1 eV, compared with that of the bare tungsten electrode whose work function is about 4.5 eV (Hilscher, 2002).

2. Lamp failure mechanisms

The primary cause of fluorescent lamp failure is the depletion of the emissive coating of the lamp electrodes (van den Hoek 2002; Verderber 1985; Waymouth 1971). The emissive coating is sensitive to electrode temperature. A very high temperature (approximately 1000°C [1273 K] or higher) will evaporate the coating material, while a low temperature (approximately 700°C [973 K] or lower) will erode the coating by sputtering of electrode metal (Ji and Davis 1998). For lamps operating in the dimmed mode, lamp failure is expected to be due mainly to low electrode temperature, though it is also possible to overheat the electrode in the dimmed mode.

3. Ballast operation

Some of the factors that determine fluorescent lamp life are lamp operating current, lamp current crest factor, and supplemental electrode heating voltage. Lamp operating current directly affects light output; reducing current, as in the case of dimming, reduces light output. The American National Standards Institute (ANSI) specifies maximum current levels (to inhibit evaporation of the electrode emissive coating) and minimum current levels (to minimize electrode sputtering). ANSI, however, does not address the issue of dimming light output.

Lamp current crest factor (CCF) is the ratio of peak lamp current to the root mean square lamp current. A higher CCF, represented by a distorted wave shape, can damage electrodes and reduce lamp life. Most electronic ballasts have a CCF of less than 1.7, a satisfactory level according to ANSI. However, CCF may rise under dimmed conditions.

If the ballast cannot supply enough electrode heating to keep a proper electrode temperature, the lamp will be damaged and its life will be reduced. To preserve lamp life, most commercial dimming ballasts provide supplemental electrode heating voltage (sometimes called "electrode heating current") when lamps are operated at a dimmed condition.

Using this knowledge, LRC researchers designed three experiments to evaluate fluorescent dimming systems:

- **Characterization of fluorescent lamp electrodes –** to determine how electrode designs of different lamps and their operational characteristics will affect ballast design

- **Evaluation of dimming ballasts –** to determine how different types of dimming ballasts implement electrode heating and how these electrode heating voltages (current) vary at different dimming levels

- **Evaluation of dimming systems –** to determine the variability (in terms of electrode heating voltage and lamp current crest factor at different dimming levels) of different dimming systems (both lamps and ballasts)

III. Characterization of Lamp Electrodes

Lamp electrodes from different manufacturers may have significantly different designs. These different electrode designs may result in different characteristics, such as total mass, emissive coating weight, cold/hot resistance, and thermal capacity. These characteristics will impact the dimming ballast design for optimum performance and life. Manufacturers offer both standard-life (20,000 hour) lamps and long-life (30,000 hour) lamps. It is possible that a given manufacturer could use a different electrode design for its long-life lamp.

The LRC evaluated lamp electrodes from three main lamp manufacturers: OSRAM Sylvania (manufacturer A), Philips Lighting (manufacturer B), and GE Lighting (manufacturer C). Two types of lamps were chosen from each manufacturer: the standard-life lamps (A, B, C), and the long-life lamps (Axl, Bxl, Cxl). (See Appendix F1 for specific details about electrode characterization.)

1. Electrode cold resistance

Electrode cold resistance is the electrode resistance measured at room temperature. Data from electrode cold resistance measurements are used to determine whether lamps may have similar electrode designs, and is also used to determine electrode temperature during operation (see next section). For each lamp type selected, six electrodes from three lamp samples were measured (each lamp has two electrodes). Figure 1 summarizes the measurement results. The error bars show the standard deviation of the measurement of the six electrodes of each type. Figure 1 illustrates that the average electrode cold resistances range from 2.40 Ω to 2.75 Ω. Two tailed T-tests with confidence level p=0.05 were performed while applying the Bon-ferroni correction on the electrode cold resistance measurement results. The analysis indicated that among the 15 total combinations for the six electrode types, there were five statistically significant differences. These were between electrodes A and Cxl, between A and Bxl, between Axl and Cxl, between A and B, and between C and Cxl. The remaining 10 combinations were not statistically different with each other. The cold resistance data indicates a possible difference in electrode designs between manufacturers. The data also indicates that the cold electrode resistances for both the standard-life and the extended-life lamps for manufacturer A were approximately the same. This was also true for manufacturer B. For manufacturer C, the long-life lamps had a significantly different electrode cold resistance than the standard-life lamps. This suggests that there may be four electrode designs among the six lamp types.

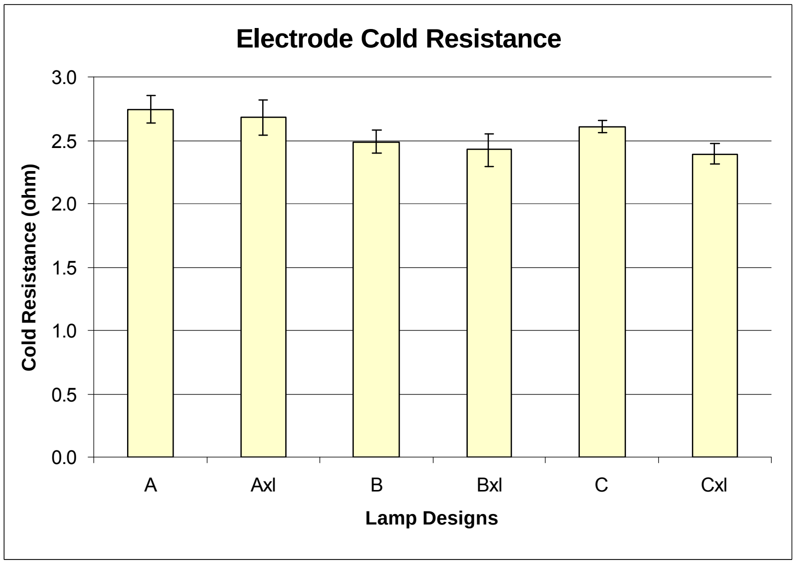

Fig. 1: Electrode cold resistance measurement results.

2. Electrode temperature and electrode heating

When an electrode is heated by a current passing through it, both its temperature and resistance rise. ANSI C78.1-1991 calls for an electrode heating voltage between 2.5 V and 4.4 V impressed across the common 4-foot F32T8 lamp electrode (equivalent to an 11 Ω resistor at normal operation) to heat it up to the nominal emission temperature. The question is: for different electrode designs, how much heating voltage is needed to heat the electrode to the nominal emission temperature at different dimming levels? Experiments were conducted to answer this question. Figure 2 illustrates the relationship between electrode temperature and electrode heating voltage for the six different lamps. Figure 2 shows that the six lamps all heated to 750 K using a 3.00 V heating voltage. This temperature is due only to the supplemental heating and does not include the joule heating due to lamp current. It was observed that all lamp types seem to converge at 3.00 V electrode heating voltage. ANSI states that the nominal electrode heating voltage value for non-dimming rapid-start ballasts is 3.60 V.

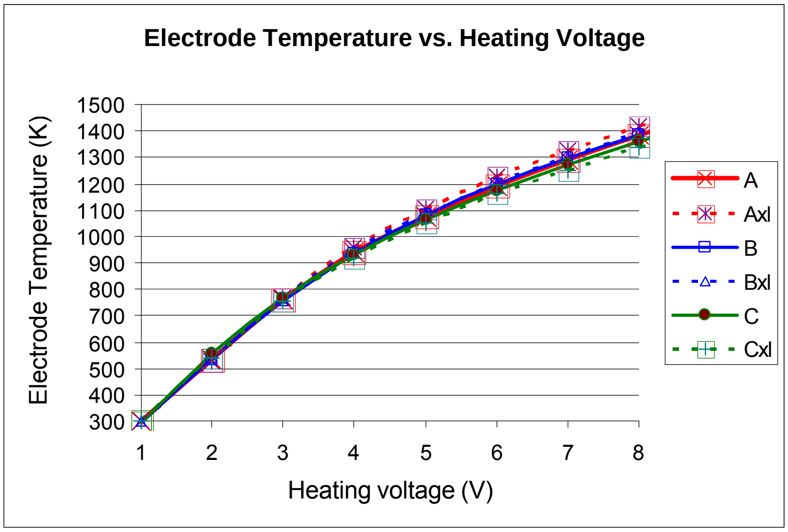

Fig. 2: The relationship between electrode temperature and heating voltage.

Some ballast designs could possibly regulate the power delivered to the electrode directly. Figure 3 illustrates the relationship between electrode temperature and electrode heating power for the six different lamps. Figure 4 shows the heating powers to heat the electrode to 750 K are similar for all six lamps.

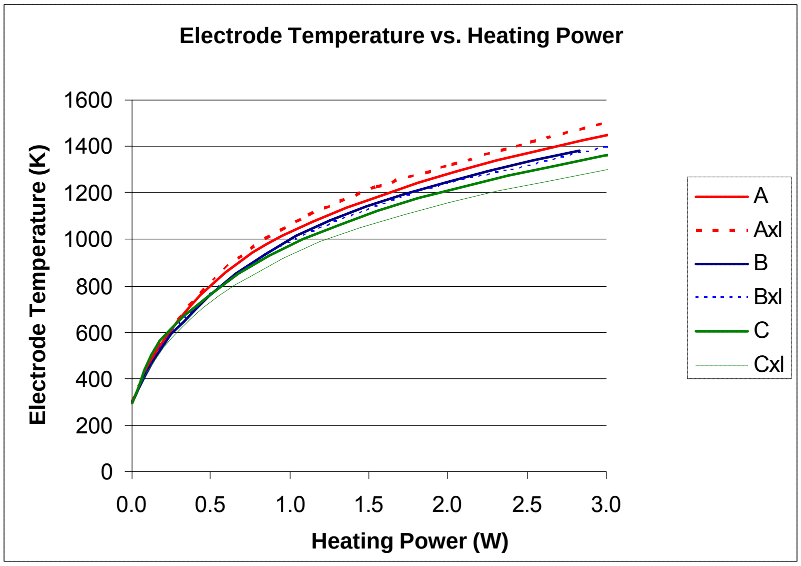

Fig. 3: The relationship between electrode temperature and heating power.

From Figure 2 and Figure 3, it can be concluded that although the electrode designs for existing 4-foot F32T8 linear lamps may be different, they are all designed to dissipate heat in a similar manner under controlled conditions (i.e., using a d.c. power supply in place of a ballast). Section V describes the difference in lamp performance when operated on an actual ballast.

3. Electrode thermal capacity

Electrode thermal capacity defines how long it takes an electrode to achieve a desired temperature when it is heated by a constant voltage. Thermal capacity will affect the lamp starting process but should not be much of an influence for stable operation. Figure 4 illustrates the electrode thermal capacity measurement results, which show that electrodes from different manufacturers have significantly different heat capacities.

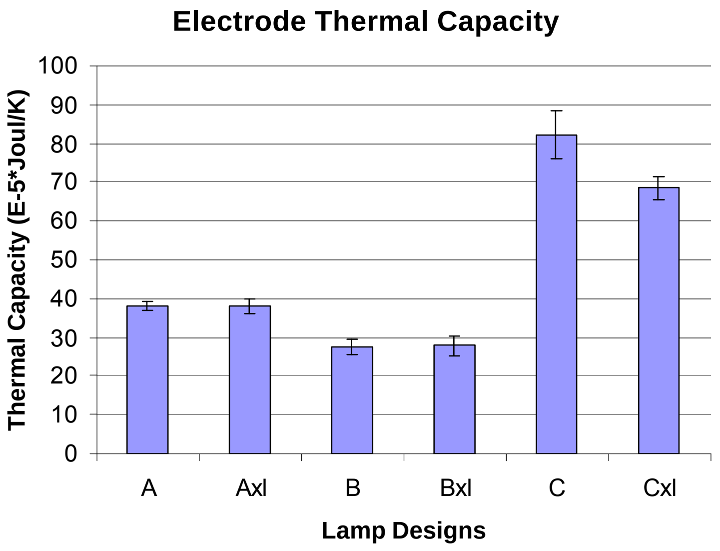

Fig. 4: Electrode heat capacity for different lamp designs.

Two tailed T-statistics with confidence level p=0.05 were performed while applying the Bon-ferroni correction on the electrode cold resistance measurement results. The analysis indicated that among the 15 total combinations for the six electrode types, there was no statistically significant difference between electrode A and Axl, and between B and Bxl. The remaining 13 combinations are statistically different with each other. The electrode thermal capacity from manufacturer C is almost double manufacturer A’s value and triple manufacturer B’s value. However, for manufacturers A and B, the long-life lamps have the same electrode thermal capacity as the standard-life lamps. The LRC researchers believe these manufacturers use the same electrode design for their respective long-life and standard-life lamps. For manufacturer C, the long-life lamps have a different electrode thermal capacity than the standard-life lamps. The LRC researchers think manufacturer C employs a different electrode design for its long-life lamps.

In summary, measurements of electrode cold resistance and thermal capacity show differences among electrode designs: electrode A (same as Axl); electrode B (same as Bxl); electrode C and electrode Cxl, for a total of four different electrode designs. These differences may impact lamp performance and dimming conditions.

IV. Evaluation of the variability of dimming ballasts on the market

As mentioned earlier, the operational life of fluorescent lamps is limited by evaporation and sputtering of the electrode coating. If the electrodes are heated too much, lamp life is reduced by evaporation of the emissive coating. On the other hand, too little heat will reduce lamp life due to sputtering. Following these arguments, an optimum supplemental electrode heating voltage (or current) exists for lamp dimming as a function of the discharge current. Supplemental heating must be maintained in order to keep lamp life within a reasonable range.

The goal of this task was to investigate how different types of dimming ballasts on the market implement electrode heating and how these electrode heating voltages (currents) vary at different dimming levels. (See Appendix F2 for details about this experiment.)

1. Dimming electronic ballasts

Electrode heating voltage and current, and lamp voltage and current were evaluated for this experiment. Twelve types of dimming electronic ballasts from six manufacturers were identified. The products used in this experiment represent all the T8 fluorescent dimming electronic ballasts on the market that the LRC could obtain at the start of this project. Three samples for each ballast type were purchased for the experiments.

2. Measurement circuits

In order to eliminate the impact of a lamp's variability and instability on the ballast measurement results, a simulated lamp made from a series of resistors was used as the dummy load for the dimming ballast evaluation. An 11 Ω resistance was used to simulate the lamp electrodes, and the positive column of the lamp was simulated by using load impedances at four different dimming levels with resistances of 750 Ω, 1000 Ω, 1500 Ω, and 2000 Ω. These impedances represent approximately 100%, 80%, 50%, and 40% of full light output, respectively. Figure 5 illustrates a simplified schematic of the evaluation circuits.

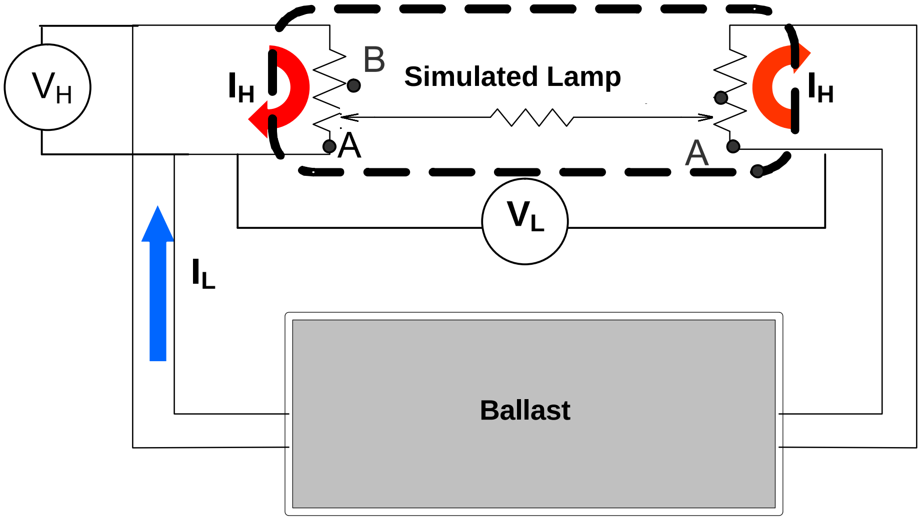

Fig. 5: A simplified schematic of the dimming ballast evaluation circuit with dummy load.

3. Results

Figure 6 shows the dimming ballast electrode heating current at the four dummy load impedances. The error bars illustrate the standard deviation of the measurements for three dimming ballast samples for each ballast type. The figure shows that the variations for the three samples from the same manufacturer are quite small, while the variations between different types of ballasts are quite large. The electrode heating currents ranged from 230 mA to 570 mA for ballasts from different manufacturers at the 100% light output condition. At the 40% light output condition, the electrode heating currents ranged from 250 mA to 450 mA. The electrode heating voltages ranged from 2.5 V to 4.5 V at the 100% light output condition. At the 40% light output condition, the electrode heating voltage ranged from 2.6 V to 5.0 V. Additionally, when the lamp current was reduced (i.e., load impedance increased), the dimming ballast manufacturers each implemented different supplemental electrode heating strategies; half of the ballast types increased the electrode heating current and voltage to compensate for electrode heating loss at dimmed conditions. However, there were manufacturers that chose to keep the electrode heating constant or even decrease the electrode heating when the lamp was dimmed.

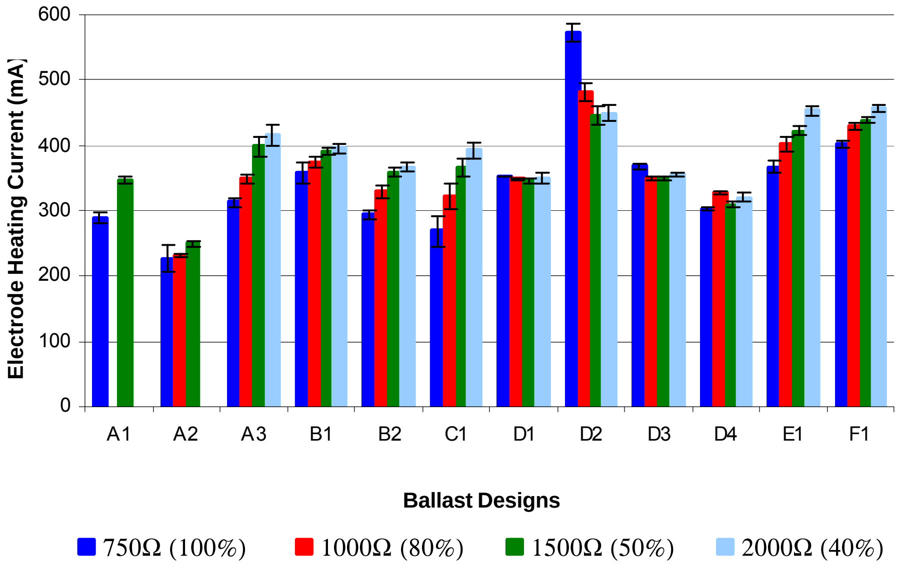

Fig. 6: Dimming ballast electrode heating current at different simulated lamp impedances.

Figure 7 illustrates a few examples of the dimming ballast electrode heating current waveforms. (See Appendix F2 for waveforms of all ballasts tested.) The figure shows dimming ballasts with dramatically different waveforms. Some ballasts, such as D1 and F1 (bottom row), have more high frequency components, compared with ballasts such as A1 (top left). D1 and F1 are more sensitive to high frequency attenuation, and the lead wire length and circuit grounding will have more of an impact on these particular ballasts.

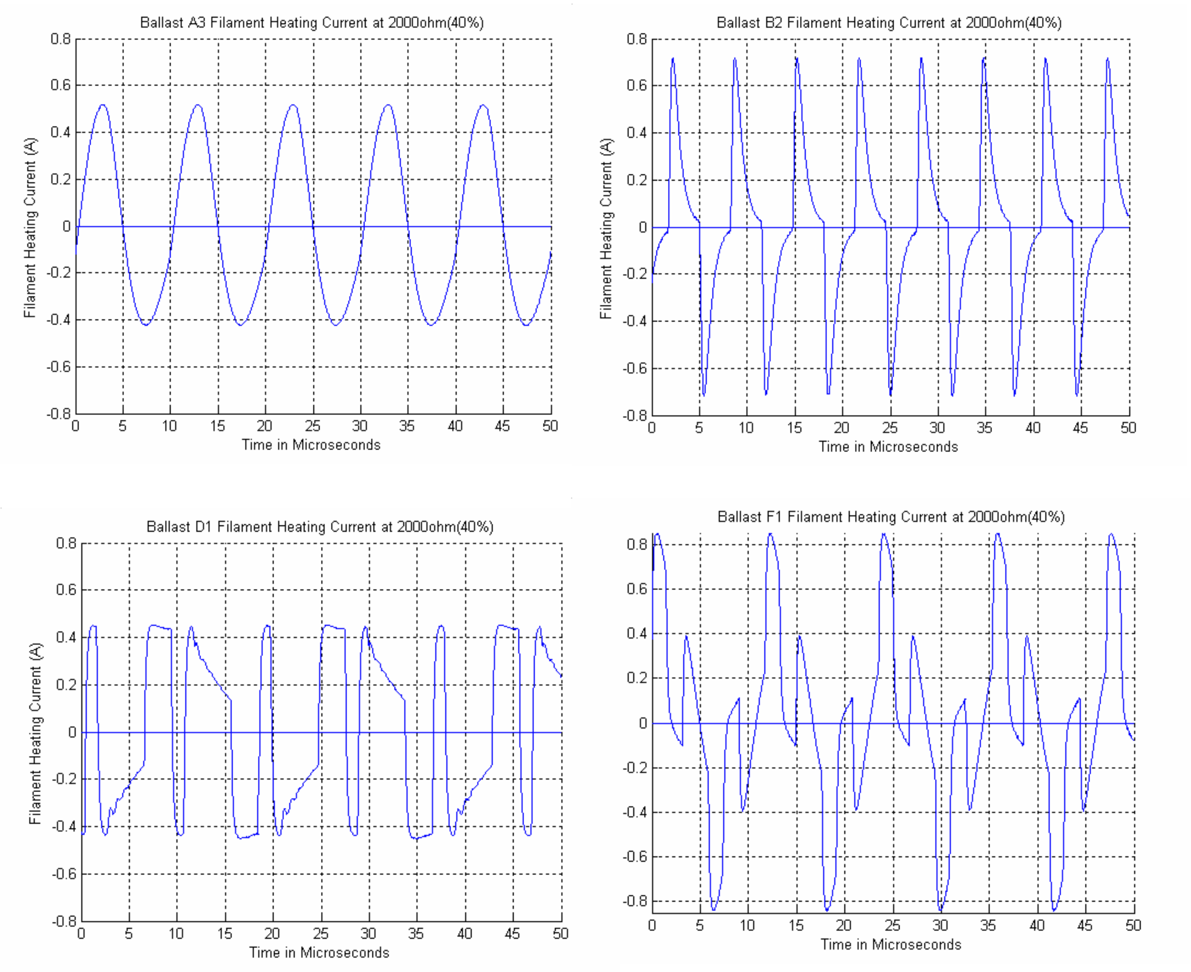

Fig. 7: Examples of dimming ballast electrode heating current waveforms.

Clearly, the ballast industry has not reached a consensus on how much electrode heating their dimming ballasts should supply and on what to do (increase or decrease electrode heating) when the lamp is operated at dimmed conditions. The variability in the electrode heating waveforms could also affect lamp performance.

V. Evaluation of the variability of dimming systems on the market

The goal of this task was to investigate the variability (in terms of electrode heating voltage and lamp current crest factor at different dimming levels) of different dimming systems (both lamps and ballasts) on the market. The results of this study will be helpful for improving dimming system performance and for drafting an industry standard for dimming electronic ballasts. (See Appendix F3 for details about this experiment.)

1. Dimming ballast and lamp systems

Twelve types of dimming ballasts and four types of fluorescent lamps (Lamp A, B, C, and Cxl as shown Appendix F1) were employed for the evaluation of dimming systems. The 48 dimming systems were evaluated at four different dimming levels. Lamp currents for the four dimming levels were the same as those used to evaluate the dimming ballasts on the dummy load, as described in section IV.

2. Results

Figure 8 shows the lamp current crest factors of the tested dimming systems at four dimming levels. Except on one dimming ballast, current crest factors remained lower than 1.7 (in most cases, lower than 1.4), as required by ANSI C82.11-2002. Figure 9 shows the lamp current waveform on the dimming ballast with a high lamp current crest factor. LRC researchers believe that lamp life could be reduced on this ballast when operated at the lower dimmed conditions.

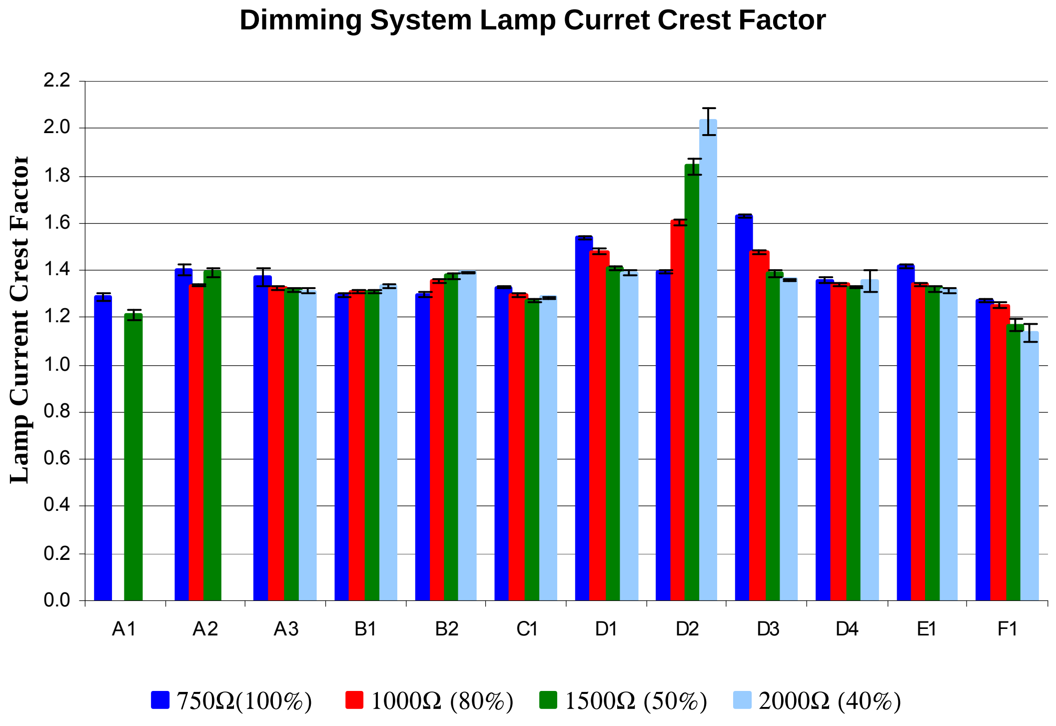

Fig. 8: Lamp current crest factors on different dimming ballasts at four dimming levels.

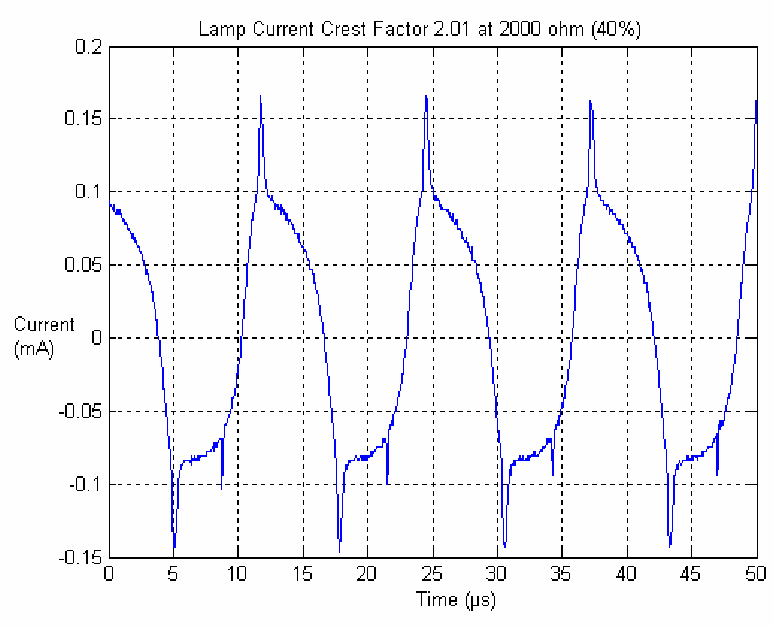

Fig. 9: Lamp current waveform for the dimming ballast (D2) with a high CCF.

Figure 10 shows the dimming system electrode heating voltage at the four dimming levels. The error bars in this figure represent the standard deviation of the measurements with the four types of lamps combined. (See Table 9 in Appendix F3 for details.) Figure 11 shows the dimming system electrode heating voltage at the four dimming levels for each of the four lamp types, and also includes data for the dummy load electrode. (See Table 10 in Appendix F3 for details.) The figures show that the variations between different lamps on the same ballast are quite small for a given dimmed condition, while the variations between different types of ballasts are quite large. The electrode heating voltages range from 2.6 V to 4.1 V for different ballast types at the 100% light output condition. At the 40% light output condition, the electrode heating voltages range from 3.8 V to 5.7 V. Additionally, when the lamp current is reduced, different dimming ballast manufacturers implement different supplemental electrode heating strategies; half of the ballast designs increase the electrode heating voltage to compensate for electrode heating loss at dimmed conditions. Again, as described in section IV, some manufacturers chose to keep the electrode heating constant. Once again, it is clear that the dimming ballast industry has not reached a consensus on how much electrode heating their dimming ballasts should supply and on what to do (increase or decrease electrode heating) when the lamp is operated at dimmed conditions. Ballasts D1 and D2 performed erratically during this test; therefore, their data is not presented here.

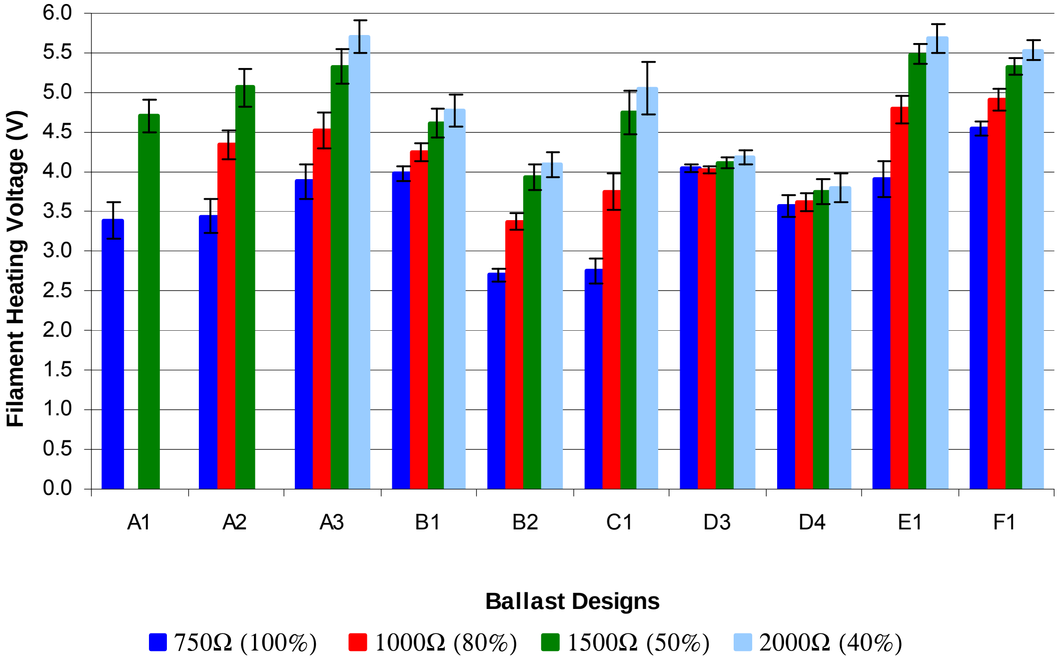

Fig. 10: Dimming ballast electrode heating voltage at four dimming levels.

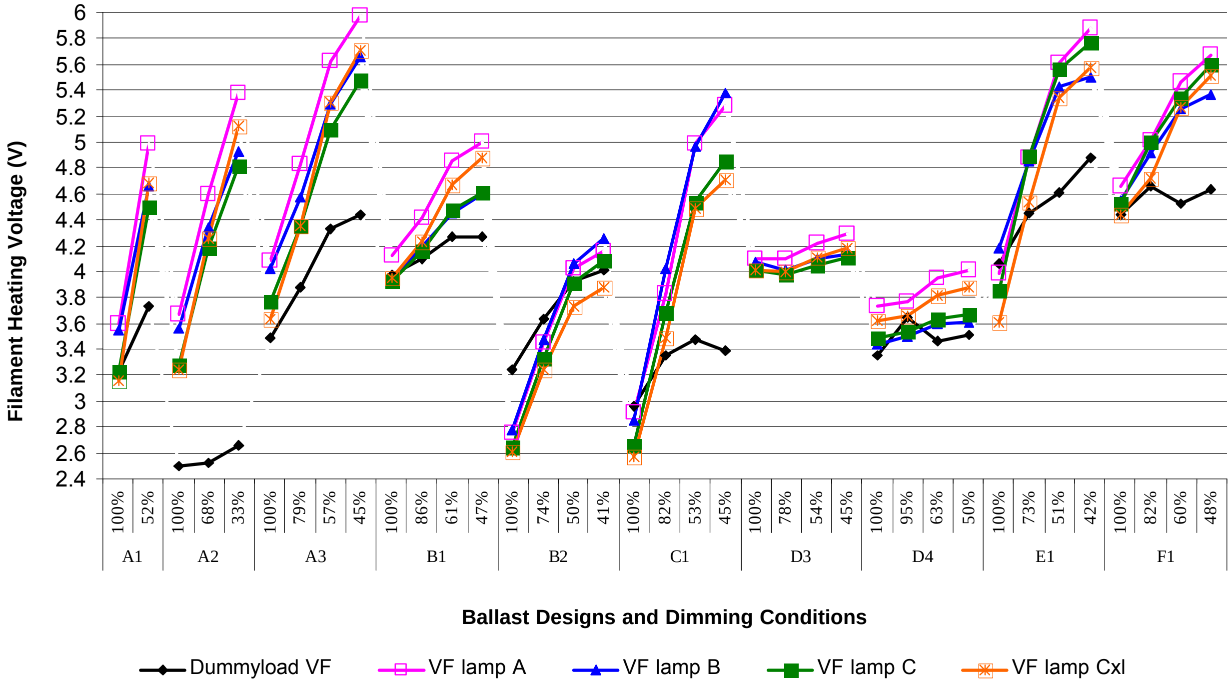

Fig. 11: Dimming ballast electrode heating voltage at four dimming levels for each lamp type

It is also important to point out that when talking about dimming systems one usually refers to the percentage of total light output, such as 100% of full light output or 40% of full light output. This does not mean that all these systems have the same light output at the same percentage. Ballast factor, which is related to lamp current and light output, needs to be taken into account in addition to the dimming condition. The lamp currents, as shown in Figure 12, for the dimming systems ranged from 168 mA to 233 mA for the 100% of full light output condition. This range relates to approximately ±20% of rated light output. This tolerance leads to more variation in dimming performance across systems.

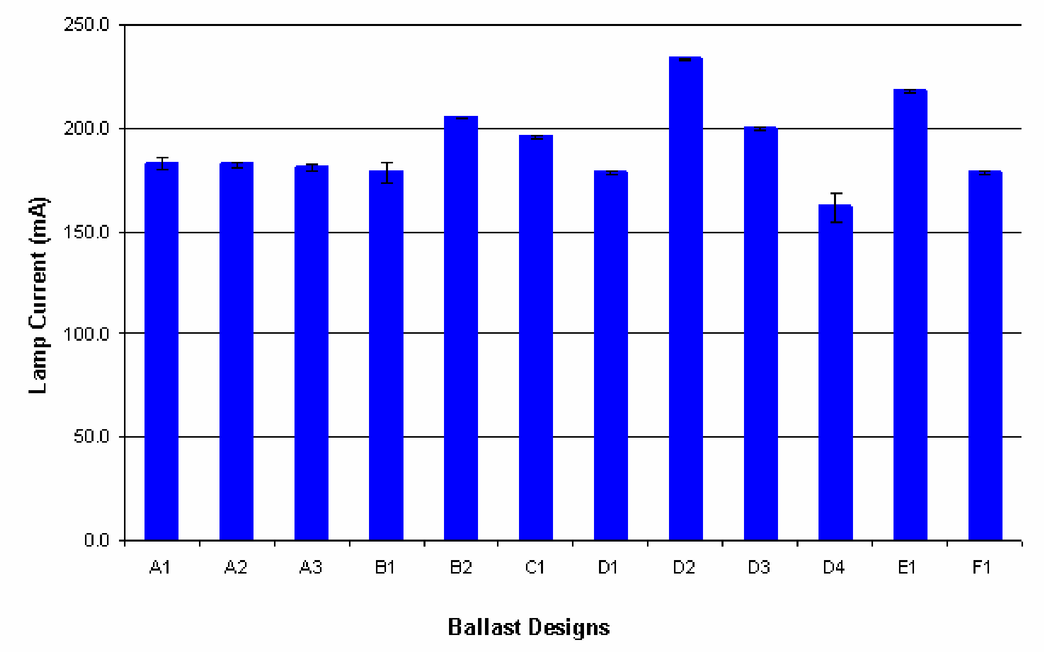

Fig. 12: Lamp current at 100% light output for each ballast type.

3. Conclusions

Overall, dimming system performance depends on the type of ballast selected, and in some cases may depend on the type of lamp used with a specific ballast. Both ballast and lamp variability may have a negative impact on life and overall system efficacy. Even without a negative impact on life, choosing a lamp-ballast combination that offers greater system efficiency is important.

More research is required to determine the impacts of dimming on lamp life. Based on the lamp and ballast variability shown in the experiments described here, a life test would be appropriate. The data obtained from this study will be helpful in the development of a life test plan. Additionally, the data will help in choosing the best lamp-ballast combination for the most efficient system.

Another important outcome of this study was the realization of how sensitive these dimming systems are to the measurement process. Testing activities can impact the measurement results and the overall system performance. More detailed testing procedures are likely needed for industry-wide testing.

VI. Acknowledgements

The Lighting Research Center gratefully acknowledges the U.S. Department of Energy and the Capturing the Daylight Dividends program for providing the financial support for this project. In addition, Rich Pysar is thanked for building the ballast evaluation apparatus for this study. Joe Canterino is thanked for help in performing the experimental tests. Jennifer Taylor is thanked for editing the report.

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Appendix F1 – Characterization of Lamp Electrodes

Lamps evaluated

Table 1 lists the lamps used in this evaluation. All the lamps are low mercury, 4-foot linear T8 fluorescent lamps. All lamps were seasoned for 100 hours at room temperature on Howard Industries instant-start electronic ballasts (Model No. E4/32IS-120) prior to the experiments.

Table 1: Fluorescent lamps used to evaluate lamp electrodes.

4-foot linear T8 Fluorescent Lamps (Low Mercury)				
Lamp No.	Brand Name	Order Code	Model Number	Rated Life
OSRAM Sylvania				
A	OCTRON	21781	FO32/841/ECO	20,000
Axl	OCTRON XPS	21681	FO32/841/XPS/ECO	30,000
Philips Lighting				
B	Universal Start Fluorescent Lamps	24671-0	F32T8/TL841/ALTO	20,000
Bxl	Advantage Performance Lamps	27066-0	F32T8/ADV841/ALTO	30,000
GE Lighting				
C	T8 ECOLUX	26668	F32T8/SP41/ECO	20,000
Cxl	T8 Starcoat SXL Ecolux	49779	F32T8/SXL/SP41/ECO	30,000

Electrode cold resistance

Electrode cold resistance was measured with a digital multi-meter (Agilent 34401A) using a four wire Kelvin Probe (Agilent 11059A) accessory. Table 2 shows the cold resistance values for each of the lamps tested.

Table 2: Electrode cold resistance values for each of the lamps tested.

Electrode Cold Resistance						
	Lamp Type					
	A	**Axl**	**B**	**Bxl**	**C**	**Cxl**
Electrode	Ω	Ω	Ω	Ω	Ω	Ω
1	2.89	2.73	2.62	2.45	2.59	2.43
2	2.68	2.85	2.44	2.51	2.53	2.33
3	2.73	2.58	2.42	2.25	2.65	2.35
4	2.60	2.50	2.38	2.58	2.59	2.42
5	2.72	2.60	2.52	2.45	2.67	2.33
6	2.84	2.83	2.55	2.30	2.61	2.52
Mean	**2.74**	**2.68**	**2.49**	**2.42**	**2.61**	**2.39**
Stdev	**0.11**	**0.14**	**0.09**	**0.12**	**0.05**	**0.08**

Electrode temperature and electrode heating

The electrode temperature can be calculated by the following equation (Mortimer 1998):

$$Th = Tc * (Rh/Rc)^{0.814} \qquad \text{Eq. (1)}$$

Where Rc is the electrode cold resistance at room temperature (Tc). Rh is the electrode hot resistance at a temperature of Th.

For this experiment, a Hewlett-Packard 3632A d.c. power supply was used to supply a constant voltage across the electrode. After the electrode current was stabilized, both the voltage and current were recorded. Electrode resistance can be calculated by Ohm’s law, and electrode temperature can be calculated from the equation (Eq. 1).

Table 3 shows the electrode heating voltage versus the electrode temperature. Table 4 shows the electrode heating power versus the electrode temperature.

Table 3: Electrode heating voltage vs. electrode temperature.

Electrode heating voltage vs. electrode temperature						
Heating Voltage (V)	**A**	**AxI**	**B**	**BxI**	**C**	**CxI**
0	297	298	299	298	297	297
1	533	541	532	529	559	536
2	756	767	762	768	763	752
3	934	945	939	959	929	920
4	1081	1088	1077	1105	1065	1054
5	1195	1205	1191	1223	1176	1160
6	1295	1300	1293	1322	1271	1252
7	1382	1393	1384	1421	1358	1336
8	Not Measured	1467	1466	1509	1435	1403

Table 4: Electrode heating power vs. electrode temperature.

Electrode heating power vs. electrode temperature			
A		**AxI**	
Heating Power (W)	**Electrode Temperature (K)**	**Heating Power (W)**	**Electrode Temperature (K)**
0	297	0.000	298
0.186	533	0.196	541
0.484	756	0.510	767
0.84	934	0.888	945
1.248	1081	1.328	1088
1.725	1195	1.830	1205
2.25	1295	2.400	1300
2.828	1382	3.003	1393
0	Not Measured	3.680	1467
B		**BxI**	
Heating Power (W)	**Electrode Temperature (K)**	**Heating Power (W)**	**Electrode Temperature (K)**
0.000	299	0.000	298
0.170	532	0.173	529
0.438	762	0.438	768
0.762	939	0.750	959
1.144	1077	1.120	1105
1.580	1191	1.545	1223
2.058	1293	2.022	1322
2.576	1384	2.520	1421
3.136	1466	3.056	1509
C		**CxI**	
Heating Power (W)	**Electrode Temperature (K)**	**Heating Power (W)**	**Electrode Temperature (K)**
0.000	297	0.000	297
0.181	559	0.207	536
0.494	763	0.546	752
0.873	929	0.960	920
1.312	1065	1.444	1054
1.815	1176	2.005	1160
2.376	1271	2.628	1252
2.982	1358	3.304	1336
3.640	1435	4.064	1403

Electrode thermal capacity

Electrode thermal capacity is defined by the following equation (Eq. 2). The equation quantifies how much energy is needed to increase the electrode temperature by one unit (Kelvin). Primarily, the equation tells how long it takes to achieve the desired temperature when the electrode is heated by a constant voltage.

$$Thermal\ Capacity = \frac{Energy}{Temperature} = \frac{I^2 * R * t}{K} \qquad \text{Eq. (2)}$$

To measure the electrode thermal capacity, a quick burst of energy was applied to the electrode in the form of a 10 ms voltage pulse of 10 Volts and the resulting temperature rise was measured. The electrode current and voltage waveforms were captured by an oscilloscope (LeCroy wave-runner, Model No. LT344L) and from the waveforms, the simultaneous electrode resistance and electrode temperature can be calculated. The energy (I^2*R*t) applied to the electrode can be calculated from the waveforms as well. Using Eq. 2, electrode heat capacity can be calculated. Table 5 shows the electrode thermal capacity.

Table 5: Electrode thermal capacity.

Electrode Thermal Capacity						
	Lamp Type					
Electrode	**A**	**Axl**	**B**	**Bxl**	**C**	**Cxl**
	J/K	J/K	J/K	J/K	J/K	J/K
1	37.9	40.9	23.8	25.0	83.0	65.9
2	38.3	37.7	28.1	28.0	76.3	71.2
3	36.7	35.4	28.9	25.1	89.5	71.0
4	38.0	37.1	28.3	28.1	75.6	69.8
5	36.9	38.8	27.8	31.4	79.2	68.5
6	40.1	37.4	27.7	29.8	89.3	64.4
Mean	**37.98**	**37.90**	**27.44**	**27.89**	**82.17**	**68.46**
Stdev	**1.22**	**1.85**	**1.83**	**2.53**	**6.20**	**2.79**

To minimize the impact of heat transfer due to radiation and convection on the measurement results, calculations were made using only the first 0.8 milliseconds of the waveforms. During such a short period, electrode temperature rose less than 30 K; thus, the impact of radiation and convection can be ignored. Figure 13 compares the results of electrode cold resistance measurements completed using the Kelvin probe with the calculated resistance from the 0.8 ms period of the waveforms. The figures shows the cold resistances from the waveform calculations are consistent with the Kelvin probe measurements.

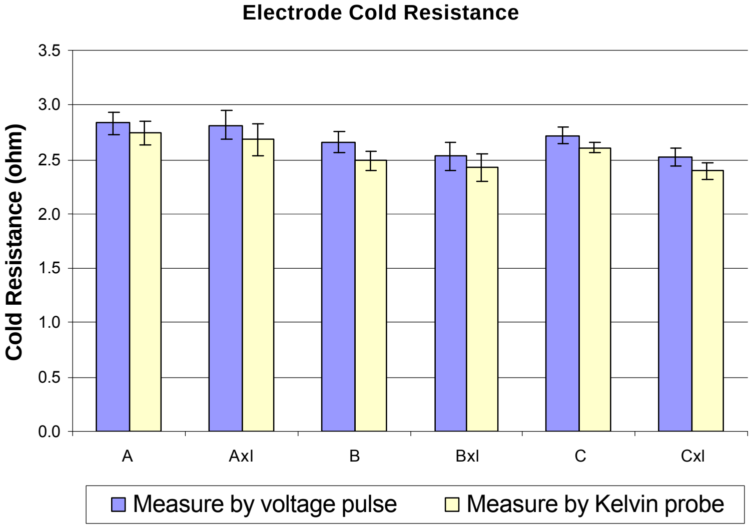


Fig. 13: Electrode resistances measured by the Kelvin probe and calculated from the waveforms.

Appendix F2 – Evaluation of the variability of dimming ballasts on the market

Dimming electronic ballasts

Table 6 details the manufacturer-supplied information of the twelve dimming electronic ballasts tested.

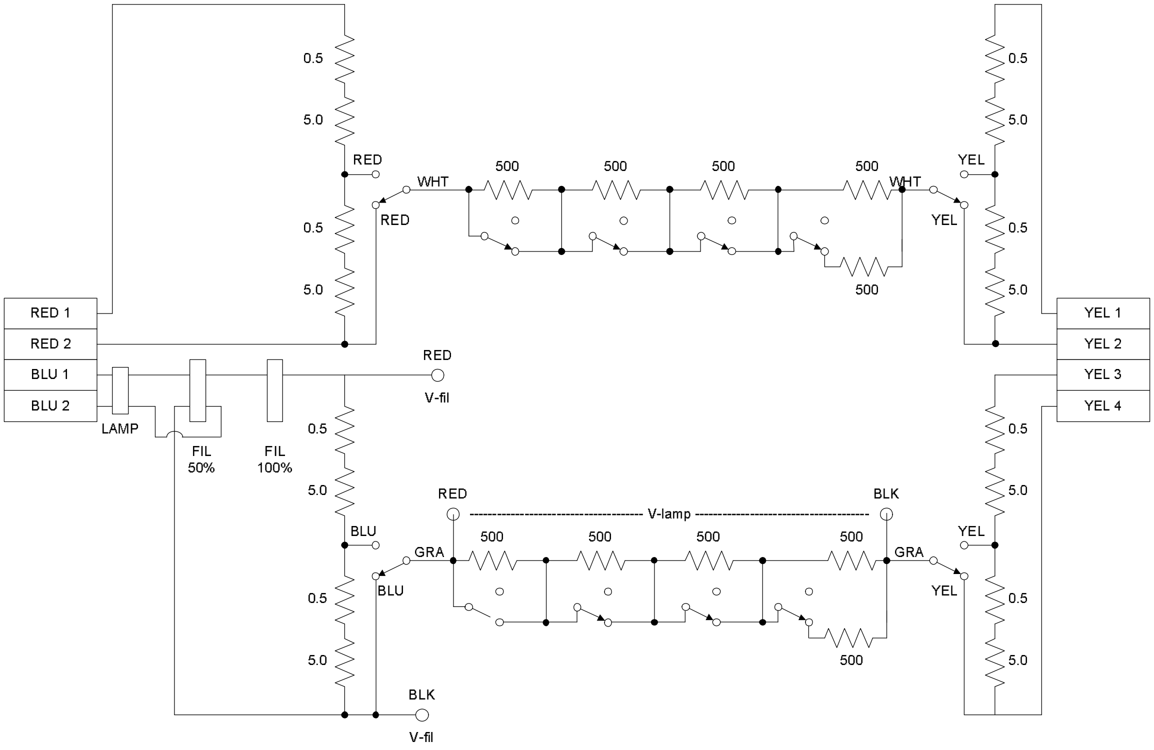
Table 6: Dimming electronic ballasts used for the experiment.

Manufacturer	Ballast No.	Trade Name	Model No.	Description	Line Current	Input Power	Ballast Factor	THD at full
Universal Lighting Technologies	A1	Ballastar S50	B232SR120S50	2 step switches preset dimming ballast,2 lamp, 120V	0.52/ 0.31	62/37	0.88/0.48	10
	A2	Ballastar S30	B232SR120S30	3 step switches preset dimming ballast,2 lamp, 120V	0.52/ 0.28/ 0.24	62/45/ 28	0.88/0.58/ 0.27	10
	A3	Ballastar V5	B232SR120V5	0-10V dimming ballast, 2 lamp, 120V	0.52/ 0.12	62/13	0.88/0.05	10
Advance Autotransformer	B1	Mark VII	RZT-2S32-SC	0-10V dimming ballast, 2 lamp, 120V	0.54	64/14	0.88/0.05	10
	B2	Mark X	REZ-2S32-SC	Powerline dimming ballast, 2 lamp, 120V	0.57	68/15	1.00/0.05	10
Sylvania	C1	HELIOS	QTP2X32T8/120DI M5 B NL	0-10V dimming ballast, 2 lamp, 120V	0.57/ 0.16	68	0.96	10
LUTRON	D1	Hi-Lume	FDB-4827_120_2	Three wire line voltage control dimming ballast, 2 lamp, 120V	0.57	n.a	>0.85	<20
	D2	Eco-10	ECO-T832-120-2	Three wire line voltage control dimming ballast, 2 lamp, 120V	0.52	n.a	>0.85	<20
	D3	Tu-wire	2W-T832-120-2	Two wire line voltage control	0.7	n.a	>0.85	<20
	D4	TVE Series	TVE-T832-120-2	0-10V dimming ballast, 2 lamp, 120V	0.55	n.a	>0.85	<20
Tridonic	E1	EXCEL	one4all	Digital controlled dimming	0.61	73	not available	<10
Lightolier	F1	Power Spec	HDF232T8UNV	HDF dimming ballast	0.57	68/13	>0.87	10

Measurement circuits

Figure 14 illustrates a more detailed circuit diagram for a two-lamp ballast scenario. The electrodes were simulated using resistors adding up to 11 Ω; the discharge regions were simulated with a series of variable resistors that could simulate the lamp impedance at the four dimming levels. The tip (as indicated by the arrow in Figure 5) of the variable resistors can move along the simulated electrode resistors. This tip movement simulates the hotspot movement along the electrode surface. In the scope of this report, the tip was fixed at point A.

When connected with a ballast, electrode heating voltage can be measured as indicated by V_H. Lamp voltage can be measured as indicated by $V_{L.}$ When the tip of the variable resistor connects at point A, I_H will be equal to the electrode heating current. To capture both the d.c. and a.c. component of the electrode heating current, a LeCroy hall-effect current probe (Model No. CP015) was used. Lamp Current I_l can be measured with a Pearson wide band current monitor (Model No. 411).



Originally, a LeCroy differential probe (Model No. ADP305) was used to measure the lamp voltage (V_L) and the electrode heating voltage (V_H). Since the lamp voltage is normally over 100 V and the electrode heating voltage is less than 10 V, the measurement of the electrode heating voltage was not accurate due to the common mode rejection sensitivity of the probe. To measure the electrode heating voltage more accurately, we employed a grounded reference voltage probe and floated the ballast input voltage. The lamp-ballast system was powered by a battery power supply (Triplite UPS power supply, model No. SU1000RT2U) to isolate it from the electrical grid and earth ground.

Experimental procedure

A pilot study was conducted to determine the dimming levels and dimming control voltage for each lamp impedance. Lamp impedances of 750 Ω, 1000 Ω, 1500 Ω and 2000 Ω were chosen for all ballasts, except for ballast A1 which used only the 750 Ω and 1500 Ω lamp impedance values. The study used the 0-10V dimming ballasts (ballasts A3, B1, C1, and D4 as shown in Table 6). Table 7 shows the pilot study results. Because the dimming ballasts are all two-lamp ballasts, Table 7 shows the measurement results for both lamps tested. For the 0-10V dimming ballasts measured on the dummy load circuit, at each dummy load impedance setting the dimming control voltages were adjusted to the same values shown in Table 7 for the corresponding lamp impedance. For the other dimming ballasts, lamp current was controlled: full lamp current corresponding to 750 Ω dummy load impedance, 145 mA corresponding to 1000 Ω dummy load impedance, 95 mA corresponding to 1500 Ω dummy load impedance, and 75 mA corresponding to 2000 Ω dummy load impedance.

Table 7: Pilot study on the dimming control voltage at different lamp impedance levels.

Ballast No.	Dimming control voltage (V)	Lamp one current (mA)	Lamp one voltage (V)	Dimming level (%)	Lamp one impedance (ohm)	Lamp two current (mA)	Lamp two voltage (V)	Dimming level (%)	Lamp one impedance (ohm)
A3	**10**	179	128	100%	713	179	125	100%	699
	7.5	170	128	95%	750	170	126	95%	740
	6.15	130	131	73%	1000	130	129	73%	992
	4.63	89	134	50%	1500	89	132	50%	1482
	3.76	67	136	37%	2000	67	133	37%	2003
B1	**10**	170	128	100%	750	169	126	100%	746
	8.1	169	128	100%	750	168	126	99%	749
	6.78	131	131	77%	1000	130	128	77%	981
	5.08	90	134	53%	1500	88	131	52%	1484
	4.12	68	136	40%	2000	67	132	39%	1985
C1	**10**	194	128	100%	658	197	123	100%	625
	5.84	172	129	88%	750	175	124	89%	712
	4.87	130	133	67%	1000	133	127	68%	953
	3.74	89	137	46%	1500	94	129	48%	1374
	3.04	70	139	36%	2000	76	130	39%	1710
D4	**10**	177	121	100%	683	177	119	100%	672
	7.92	163	122	92%	750	164	120	93%	735
	6.83	127	127	72%	1000	127	125	72%	983
	5.5	90	135	51%	1500	90	132	51%	1460
	4.65	70	140	40%	2000	71	136	40%	1914

Ballast measurement procedure

Step one: Lamp current and electrode heating current measurements

Connect the ballast and dimming controls to the measurement system and energize the power supply. Set the oscilloscope time scale to 5 ms/div, sample size 1 million samples. After 5 minutes, record the RMS lamp current and electrode heating current, and save the lamp current and electrode heating current waveform.

Step two: Electrode heating voltage measurement

Connect the electrode heating voltage probe to the measurement circuit, and record the electrode heating voltage RMS value and its waveform. Record the lamp current and electrode heating current RMS values as well.

Step three: Lamp voltage measurement

Remove the electrode heating voltage probe and connect the lamp voltage probe to the measurement circuit, and record the lamp voltage RMS value and its waveform. Record the lamp current and electrode heating current RMS values as well.

Results

Table 8 details the mean and standard deviation of the electrode heating current and voltage at the four dummy load resistance conditions. When the electrode heating voltage probe was connected to the oscilloscope, output from ballasts D2 and D3 significantly deteriorated (lamp voltage dropped to lower than 50 V). As a result, electrode heating voltages under ballast D2 and D3 were not measured.

Table 8: Electrode heating current and voltage at different dummy load resistance.

		Filament Heating Current (mA)				Filament Heating Voltage (V)			
Ballast No.		750Ω	1000Ω	1500Ω	2000Ω	750Ω	1000Ω	1500Ω	2000Ω
A1	Mean	289	Not Tested	346	Not Tested	3.23	Not Tested	3.73	Not Tested
	StDev	7		6		0.05		0.09	
A2	Mean	227	231	250	Not Tested	2.49	2.52	2.66	Not Tested
	StDev	20	3	4		0.21	0.01	0.06	
A3	Mean	312	349	398	416	3.48	3.87	4.33	4.44
	StDev	8	6	15	17	0.06	0.11	0.20	0.22
B1	Mean	358	374	391	396	3.98	4.09	4.27	4.27
	StDev	16	7	5	7	0.08	0.09	0.09	0.08
B2	Mean	294	329	359	366	3.24	3.64	3.93	4.01
	StDev	7	10	8	7	0.09	0.12	0.08	0.07
C1	Mean	269	322	365	393	2.96	3.35	3.47	3.39
	StDev	23	20	13	12	0.28	0.43	0.48	0.28
D1	Mean	352	349	346	350	3.95	3.76	3.62	3.57
	StDev	0	1	4	9	0.14	0.12	0.09	0.05
D2	Mean	574	481	447	449	Not Tested			
	StDev	14	13	14	12				
D3	Mean	368	350	350	355	Not Tested			
	StDev	4	3	2	2				
D4	Mean	302	328	309	320	3.35	3.64	3.47	3.51
	StDev	2	3	4	7	0.02	0.05	0.06	0.07
E1	Mean	366	402	422	453	4.06	4.45	4.61	4.88
	StDev	9	10	6	7	0.11	0.11	0.07	0.07
F1	Mean	401	430	438	456	4.44	4.66	4.53	4.63
	StDev	6	6	5	6	0.06	0.07	0.12	0.07

Figure 15 shows the dimming ballast electrode heating voltage at the four dummy load impedances.

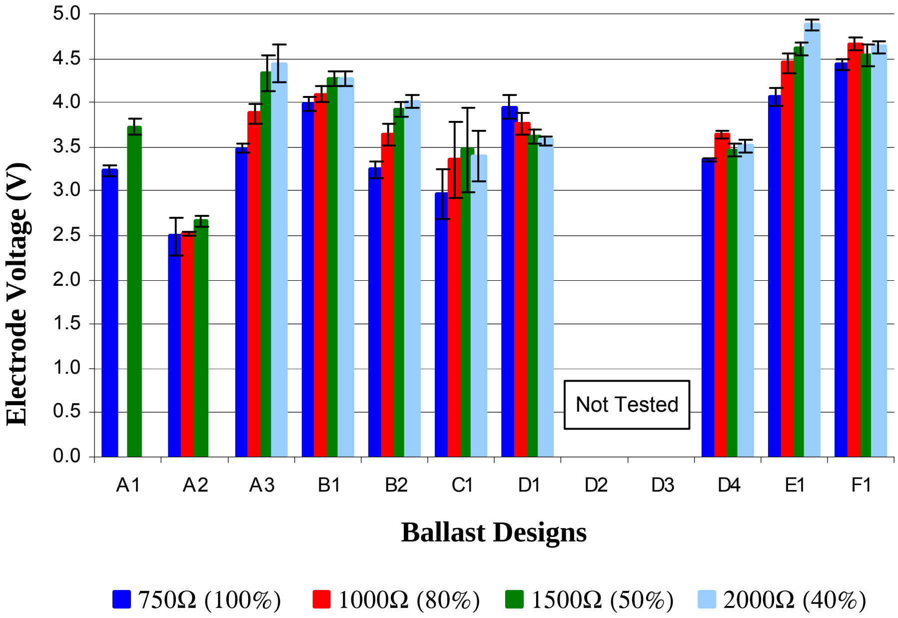
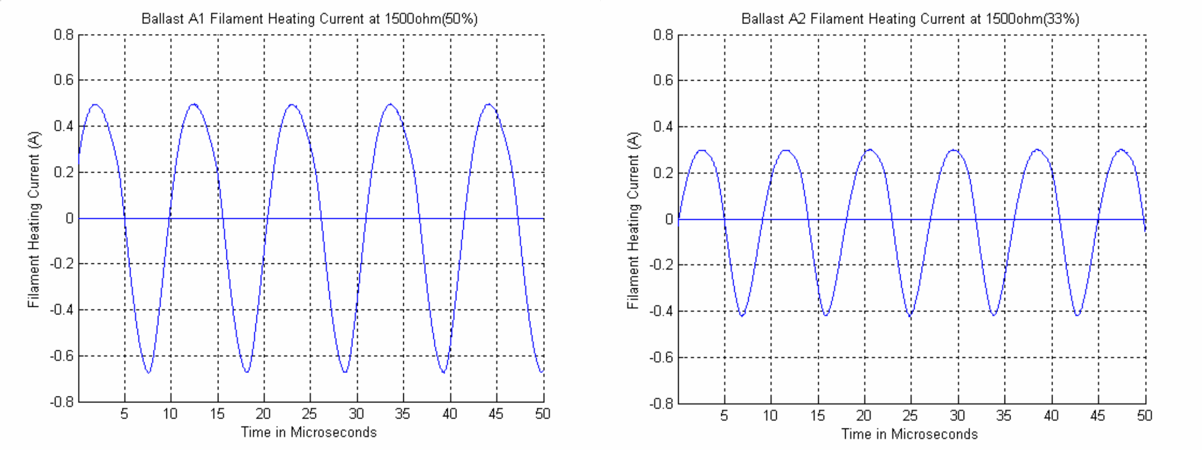
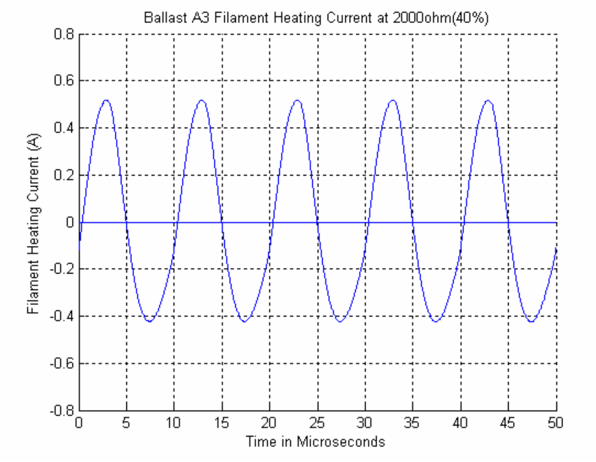


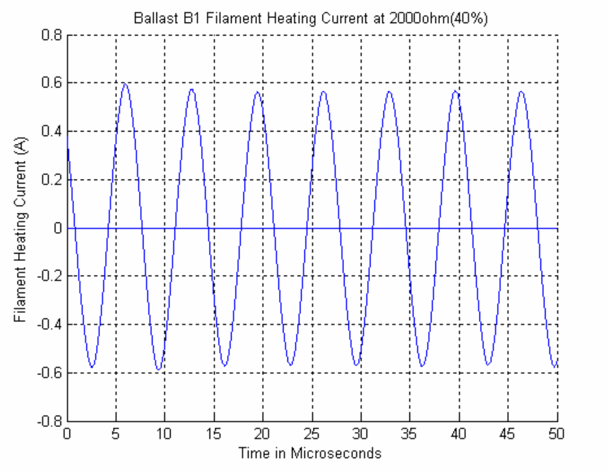
Fig. 15: Dimming ballast electrode heating voltage at different simulated lamp impedances.

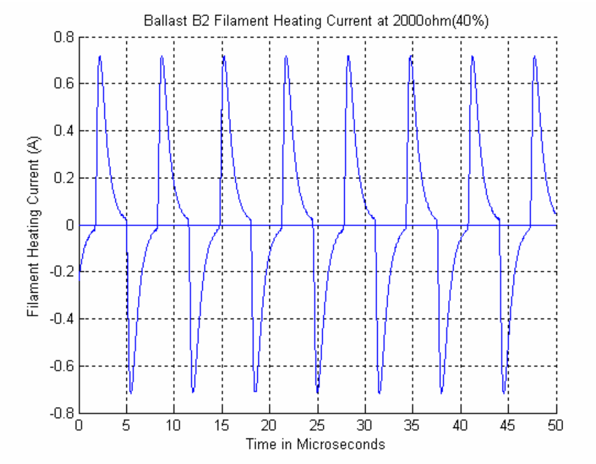
Fig. 16 shows electrode heating current waveforms for all the dimming ballasts. The waveforms are vastly different for ballasts from different manufacturers.

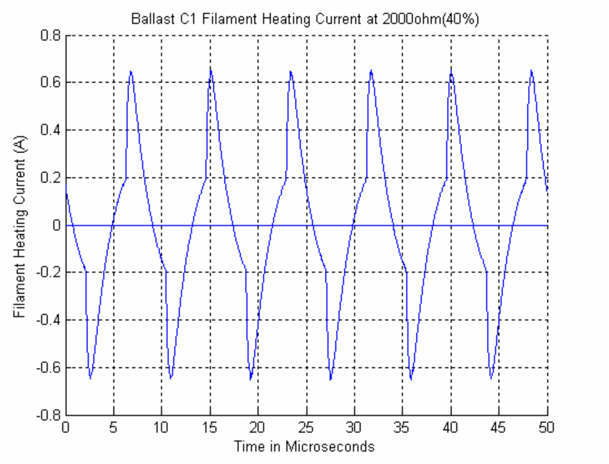
Fig. 16: Dimming ballast electrode heating current waveforms on a simulated lamp.

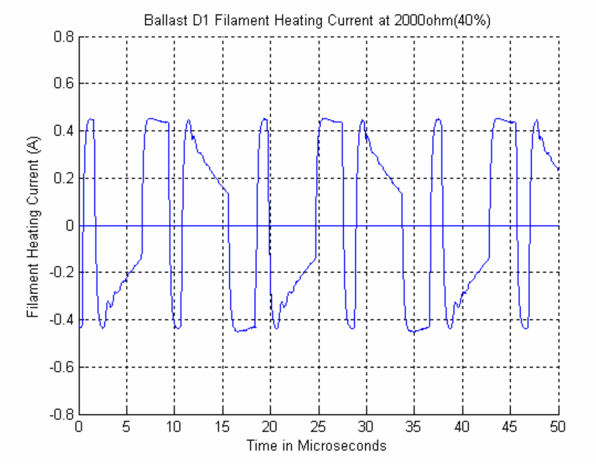


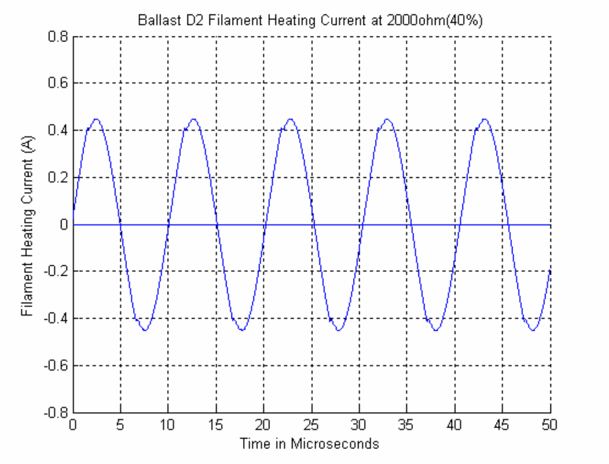

Ballast A3 Filament Heating Current at 2000ohm(40%)

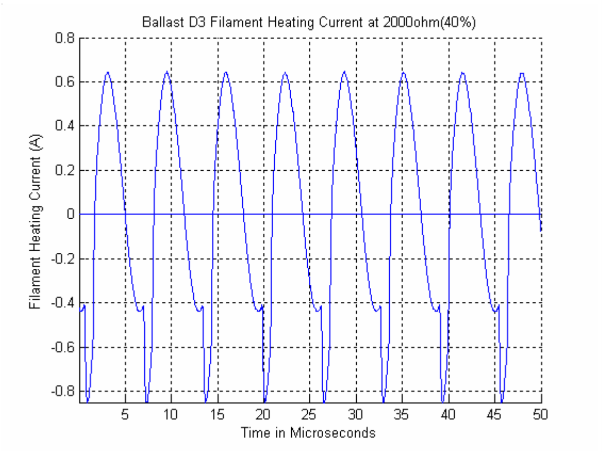

Ballast B1 Filament Heating Current at 2000ohm(40%)

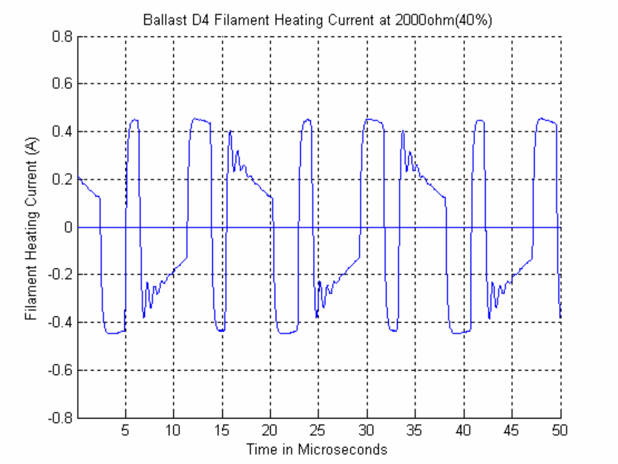

Ballast B2 Filament Heating Current at 2000ohm(40%)

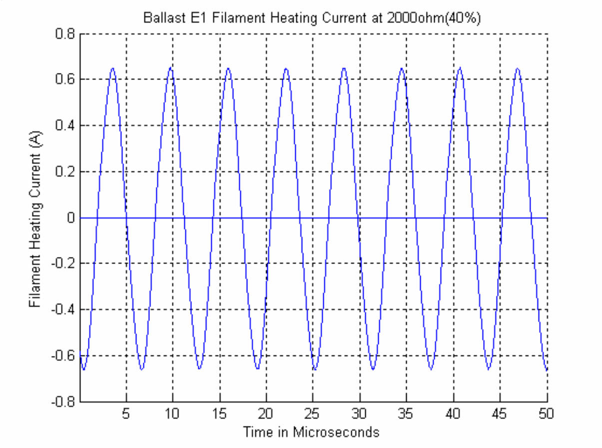

Ballast C1 Filament Heating Current at 2000ohm(40%)

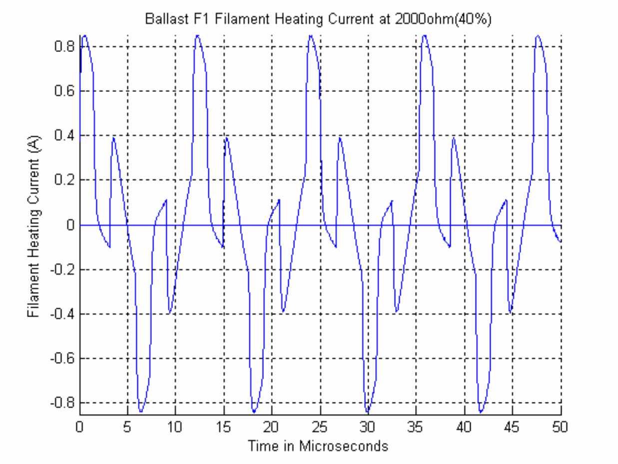

Ballast D1 Filament Heating Current at 2000ohm(40%)


Ballast D2 Filament Heating Current at 2000ohm(40%)


Ballast D3 Filament Heating Current at 200Ohm(40%)


Ballast D4 Filament Heating Current at 200Ohm(40%)


Ballast E1 Filament Heating Current at 200Ohm(40%)


Ballast F1 Filament Heating Current at 200Ohm(40%)

Appendix F3 – Evaluation of the variability of dimming systems on the market

Measurement apparatus

The measurement systems were almost the same as those used to evaluate the dimming ballasts on the dummy load, except real lamps were used instead of the simulated lamp. Figure 17 shows the schematic of the ballast system testing setup.

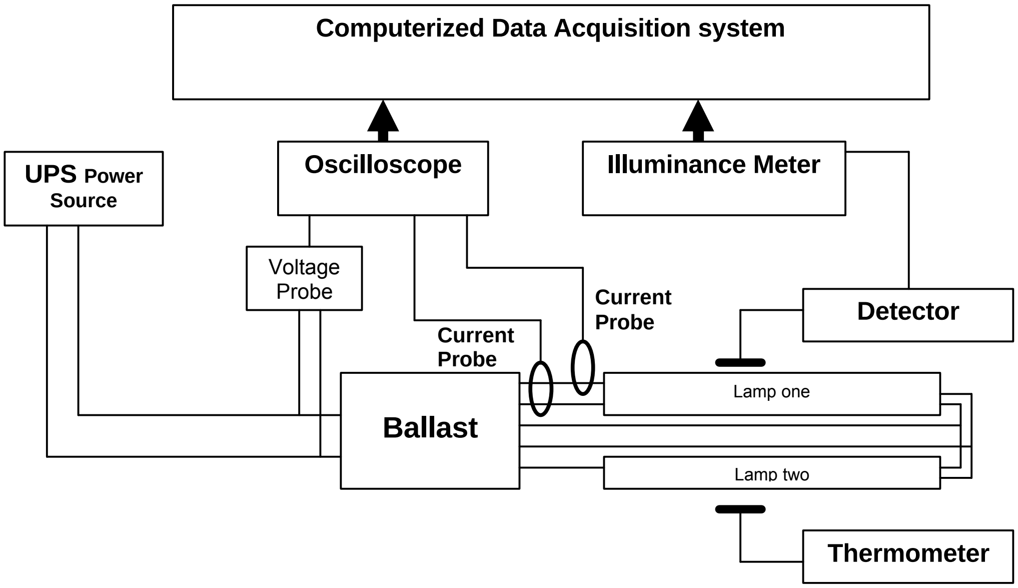


Fig. 17: Schematic of the dimming system testing setup.

Experimental procedure

Lamps were seasoned for 100 hours prior to taking measurements. For each of the twelve ballasts, four lamp types were tested at four dimming levels. The whole measurement process lasted approximately three weeks. Before measuring the dimming systems, all lamps were first measured on a programmed-start ballast (MARK-V RIC2S32). The lamps were measured again on the same programmed-start ballast after collecting data on every three ballasts. This test ensured that the lamps’ electrical characteristics remained constant throughout the entire measurement process.

Dimming systems evaluation procedure

1. Connect the dimming ballast to the circuit. Figure 17 shows the circuit diagram. Please note:
    a. The Lightolier Powerspec ballast should be connected with the electrodes in series. All the other ballasts should be connected with the electrodes in parallel.
    b. Different dimming ballasts use different dimming controls. Please follow the circuit diagram on the ballasts to connect the dimming controls.
2. Set the dimming controls to full light output.
3. Plug the power cord into the UPS power supply.
4. On the oscilloscope, Channel 1 measures electrode low end current (ILF); Channel 2 measures lamp current with the Lecroy CP015 probe (ILAC); Channel 3 measures lamp current with the Pearson probe (ILAP); Channel 4 measures electrode voltage (VLF). Check that the voltage probe (Channel 4) is not connected to the oscilloscope. Make sure the waveforms on the oscilloscope are within the display limit.
5. Adjust the dimming control to ensure that the lamp current on Channel 2 is the same one used to evaluate the dimming ballast on the dummy load.
6. Wait about 15 minutes, then check the light output stabilization program on the computer screen to ensure the lamp is stabilized.
7. Unplug the UPS power supply from the wall plug (This is to avoid dual ground).
8. Set the oscilloscope time/div to 5ms/div, and record the average value of Channels 1, 2, and 3 on the oscilloscope. Set the oscilloscope time/div to 10 micro-second/div. Press the oscilloscope STOP button. Save Channels 1, 2 and 3 waveforms to the computer (using the LABVIEW Lecroysave2.vi program).
9. Ensure that the UPS is unplugged from the wall plug. Connect the electrode heating voltage probe to Channel 4, set the oscilloscope time/div to 5 ms/div, and record the RMS value. Set the oscilloscope time/div to 10 micro-second/div. Press the oscilloscope STOP button and save its waveform.
10. Change the dimming control to another dimming level, and repeat steps 5-9.

Results

Table 9 summarizes the mean and standard deviation of the measurement results of dimming ballast and lamp systems. Table 10 shows more detailed measurement results. When the electrode heating voltage probe was connected to the oscilloscope, the lamp started to flicker on dimming ballast D1 and D2. Therefore, electrode heating voltages on ballast D1 and D2 were not measured.

Table 9: Measurement results of dimming ballast and lamp systems.

Ballast No.	Dimming Level	Statistics	Electrode Heating Current (mA)	Current Crest Factor	Lamp Current	Electrode Heating Voltage (V)
A1	100%	Mean	261	1.29	183.0	3.38
		StDev	18	0.02	3.1	0.22
	51%	Mean	322	1.21	85.1	4.70
		StDev	31	0.02	1.4	0.20
A2	100%	Mean	266	1.40	182.4	3.44
		StDev	23	0.02	1.5	0.21
	68%	Mean	305	1.34	114.3	4.34
		StDev	30	0.01	1.2	0.18
	33%	Mean	343	1.39	54.3	5.06
		StDev	39	0.02	1.5	0.24
A3	100%	Mean	391	1.37	181.0	3.88
		StDev	15	0.04	1.3	0.21
	79%	Mean	410	1.32	136.0	4.52
		StDev	23	0.01	2.7	0.22
	56%	Mean	422	1.31	93.5	5.33
		StDev	32	0.01	2.0	0.21
	44%	Mean	426	1.31	71.4	5.70
		StDev	40	0.01	1.2	0.21
B1	100%	Mean	268	1.29	178.4	3.98
		StDev	32	0.01	4.7	0.09
	84%	Mean	285	1.31	143.9	4.25
		StDev	35	0.01	2.1	0.11
	60%	Mean	308	1.31	98.5	4.61
		StDev	37	0.01	1.9	0.19
	46%	Mean	322	1.33	74.3	4.77
		StDev	41	0.01	2.1	0.20
B2	100%	Mean	233	1.30	204.7	2.70
		StDev	15	0.01	0.1	0.08
	76%	Mean	262	1.35	143.8	3.37
		StDev	21	0.01	3.5	0.11
	52%	Mean	290	1.37	94.0	3.93
		StDev	24	0.01	2.5	0.15
	42%	Mean	299	1.39	75.9	4.09
		StDev	25	0.00	2.2	0.16
C1	100%	Mean	230	1.33	195.8	2.75
		StDev	14	0.00	1.0	0.16
	79%	Mean	281	1.29	143.5	3.75
		StDev	20	0.01	3.9	0.23
	54%	Mean	322	1.27	93.5	4.74
		StDev	29	0.01	4.2	0.27
	45%	Mean	336	1.28	75.6	5.05
		StDev	28	0.00	1.4	0.33

Ballast No.	Dimming Level	Statistics	Electrode Heating Current (mA)	Current Crest Factor	Lamp Current	Electrode Heating Voltage (V)
D1	100%	Mean	388	1.54	178.4	Not Tested
		StDev	32	0.01	0.7	
	81%	Mean	371	1.48	138.5	
		StDev	30	0.01	5.4	
	58%	Mean	354	1.41	95.1	
		StDev	31	0.01	3.1	
	48%	Mean	349	1.39	76.0	
		StDev	32	0.01	2.7	
D2	100%	Mean	496	1.40	233.3	Not Tested
		StDev	33	0.01	0.6	
	68%	Mean	445	1.60	144.8	
		StDev	32	0.01	4.0	
	44%	Mean	424	1.84	94.5	
		StDev	40	0.03	1.6	
	34%	Mean	417	2.03	76.6	
		StDev	44	0.06	2.4	
D3	100%	Mean	396	1.55	199.9	4.05
		StDev	28	0.00	1.1	0.04
	76%	Mean	372	1.47	144.7	4.02
		StDev	29	0.01	0.3	0.06
	53%	Mean	351	1.38	94.2	4.11
		StDev	31	0.02	0.1	0.07
	44%	Mean	345	1.36	77.1	4.18
		StDev	31	0.00	0.3	0.08
D4	100%	Mean	259	1.36	161.6	3.57
		StDev	29	0.01	6.8	0.13
	91%	Mean	264	1.34	145.1	3.61
		StDev	28	0.01	2.2	0.12
	63%	Mean	280	1.33	92.9	3.75
		StDev	29	0.00	1.3	0.17
	52%	Mean	282	1.35	73.7	3.79
		StDev	24	0.05	1.2	0.19
E1	100%	Mean	276	1.42	217.8	3.91
		StDev	22	0.01	1.0	0.24
	73%	Mean	303	1.34	147.3	4.79
		StDev	28	0.01	1.0	0.17
	51%	Mean	335	1.32	95.2	5.49
		StDev	36	0.01	1.3	0.13
	42%	Mean	349	1.31	75.5	5.68
		StDev	39	0.01	0.5	0.17
F1	100%	Mean	456	1.27	178.6	4.54
		StDev	25	0.01	1.1	0.09
	83%	Mean	440	1.25	145.1	4.91
		StDev	21	0.01	1.0	0.14
	58%	Mean	418	1.17	96.9	5.33
		StDev	13	0.02	1.0	0.09
	47%	Mean	417	1.14	80.7	5.53
		StDev	21	0.04	9.7	0.13

Table 10: Evaluation of dimming ballasts and lamp systems.

Ballast Trade Name	Ballast No.	Lamp No.	Dimming Level	Filament Current (mA)	Current Crest Factor	Lamp Current (mA)	Filament Voltage (V)	Dummy Load Filament Current
Universal S50_3	A1_1	P2	100%	272.5	1.29	178.4	3.6	289
	A1_2		52%	328.7	1.24	85.3	4.982	346
Universal S30_3	A2_1	P2	100%	270	1.39	180.5	3.673	227
	A2_2		68%	308.9	1.34	113.9	4.593	231
	A2_3		33%	349.3	1.39	54.1	5.372	250
Universal V5_3	A3_1	P2	100%	400.6	1.43	179.6	4.081	312
	A3_2		79%	421.5	1.32	132.9	4.823	349
	A3_3		57%	428	1.31	92.9	5.618	398
	A3_4		45%	434	1.30	72.1	5.981	416
MARK VII_3	B1_1	P2	100%	274.5	1.31	172.4	4.123	358
	B1_2		86%	291.2	1.30	142.9	4.409	374
	B1_3		61%	310.5	1.30	96.2	4.852	391
	B1_4		47%	325.2	1.33	73.2	5.005	396
MARK X_3	B2_1	P2	100%	228.1	1.29	204.8	2.759	294
	B2_2		74%	257.9	1.35	140.7	3.448	329
	B2_3		50%	285.3	1.36	90.9	4.024	359
	B2_4		41%	292.6	1.39	74.1	4.158	366
Helios-3	C1_1	P2	100%	230.6	1.33	194.9	2.916	269
	C1_2		82%	278.7	1.29	149.0	3.831	322
	C1_3		53%	327.2	1.27	91.9	4.99	365
	C1_4		45%	342.5	1.28	74.5	5.278	393
Lutron TVE_3	D1_1	P2	100%	390.5	1.53	177.7	Not Tested	352
	D1_2		79%	369.2	1.46	132.1		349
	D1_3		57%	351.8	1.40	92.4		346
	D1_4		47%	346.2	1.40	73.7		350
Lutron Tuwire_3	D2_1	P2	100%	501.3	1.39	233.7		574
	D2_2		70%	442.2	1.62	149.6		481
	D2_3		44%	425.9	1.85	96.8		447
	D2_4		32%	421.4	2.11	77.7		449
Lutron Hilume_3	D3_1	P2	100%	394.5	1.55	198.4	4.097	368
	D3_2		78%	367.4	1.47	144.5	4.1	350
	D3_3		54%	342.9	1.36	94.1	4.218	350
	D3_4		45%	339.5	1.36	76.9	4.297	355
Lutron Eco10_3	D4_1	P2	100%	256.6	1.34	155.9	3.735	302
	D4_2		95%	260.1	1.34	146.0	3.761	328
	D4_3		63%	278.4	1.32	92.2	3.949	309
	D4_4		50%	285.3	1.34	73.3	4.014	320
Tridonic_3	E1_1	P2	100%	271.4	1.42	219.1	3.99	366
	E1_2		73%	300.3	1.34	147.4	4.878	402
	E1_3		51%	337	1.31	94.6	5.614	422
	E1_4		42%	354.2	1.33	76.1	5.877	453
Powerspec_3	F1_1	P2	100%	466.5	1.27	179.1	4.656	401
	F1_2		82%	446.7	1.26	145.4	5.007	430
	F1_3		60%	421	1.19	97.2	5.457	438
	F1_4		48%	414.1	1.16	75.7	5.665	456

Ballast Trade Name	Ballast No.	Lamp No.	Dimming Level	Filament Current (mA)	Current Crest Factor	Lamp Current (mA)	Filament Voltage (V)
Universal S50_3	A1_1	S4	100%	236	1.26	185.1	3.542
	A1_2		51%	279.6	1.19	86.8	4.654
Universal S30_3	A2_1	S4	100%	237.4	1.38	184.0	3.558
	A2_2		67%	266.2	1.33	115.8	4.346
	A2_3		33%	292.5	1.36	56.1	4.928
Universal V5_3	A3_1	S4	100%	369.8	1.35	181.3	4.027
	A3_2		80%	379.9	1.32	138.8	4.572
	A3_3		57%	381.5	1.30	95.8	5.296
	A3_4		44%	373.9	1.31	72.8	5.653
MARK VII_3	B1_1	S4	100%	232.8	1.29	182.3	3.942
	B1_2		82%	244.7	1.32	143.1	4.195
	B1_3		60%	263.5	1.30	100.5	4.456
	B1_4		46%	272.6	1.33	76.5	4.593
MARK X_3	B2_1	S4	100%	217.3	1.30	204.7	2.774
	B2_2		77%	235.9	1.36	148.9	3.471
	B2_3		53%	259.9	1.39	96.6	4.062
	B2_4		42%	269.1	1.39	77.6	4.251
Helios-3	C1_1	S4	100%	213.4	1.32	197.0	2.846
	C1_2		77%	256.1	1.29	141.6	4.02
	C1_3		55%	285.7	1.27	97.5	4.964
	C1_4		44%	299	1.29	74.3	5.377
Lutron TVE_3	D1_1	S4	100%	345.6	1.54	179.0	Not Tested
	D1_2		83%	332.7	1.49	143.0	
	D1_3		59%	315.7	1.41	97.8	
	D1_4		48%	309.2	1.38	78.4	
Lutron Tuwire_3	D2_1	S4	100%	454.9	1.39	233.9	
	D2_2		66%	407.5	1.61	146.1	
	D2_3		42%	373.9	1.86	93.9	
	D2_4		33%	362	1.98	73.5	
Lutron Hilume_3	D3_1	S4	100%	359	1.56	200.9	4.067
	D3_2		72%	335.9	1.48	145.0	4.016
	D3_3		51%	313.5	1.39	94.2	4.091
	D3_4		41%	307	1.36	77.0	4.13
Lutron Eco10_3	D4_1	S4	100%	223.9	1.38	169.3	3.44
	D4_2		86%	229.6	1.35	147.8	3.496
	D4_3		58%	242.3	1.33	91.7	3.59
	D4_4		46%	247	1.32	72.1	3.612
Tridonic_3	E1_1	S4	100%	251.3	1.42	217.5	4.176
	E1_2		73%	269.6	1.35	146.3	4.853
	E1_3		51%	288.7	1.32	96.8	5.422
	E1_4		41%	295.8	1.31	75.0	5.499
Powerspec_3	F1_1	S4	100%	430.9	No data	179.5	4.544
	F1_2		82%	418.2	No data	145.9	4.911
	F1_3		57%	399.4	No data	95.5	5.259
	F1_4		46%	392.2	No data	73.5	5.367

Ballast Trade Name	Ballast No.	Lamp No.	Dimming Level	Filament Current (mA)	Current Crest Factor	Lamp Current (mA)	Filament Voltage (V)
Universal S50_3	A1_1	G1	100%	259.7	1.30	184.7	3.225
	A1_2		51%	323	1.21	85.0	4.5
Universal S30_3	A2_1	G1	100%	264.9	1.42	182.8	3.283
	A2_2		68%	303.5	1.34	114.5	4.176
	A2_3		33%	343.8	1.41	54.4	4.822
Universal V5_3	A3_1	G1	100%	389.7	1.35	182.6	3.765
	A3_2		79%	405.7	1.33	137.5	4.349
	A3_3		56%	419.6	1.31	94.0	5.101
	A3_4		43%	424.5	1.32	70.6	5.478
MARK VII_3	B1_1	G1	100%	258.1	1.29	181.9	3.924
	B1_2		84%	275.9	1.31	147.0	4.158
	B1_3		60%	304.2	1.32	99.4	4.471
	B1_4		46%	319.5	1.34	75.5	4.614
MARK X_3	B2_1	G1	100%	232.8	1.30	204.7	2.643
	B2_2		75%	266	1.36	142.7	3.331
	B2_3		51%	296	1.37	93.1	3.914
	B2_4		41%	305.8	1.39	73.9	4.079
Helios-3	C1_1	G1	100%	227.7	1.33	196.2	2.655
	C1_2		77%	283.8	1.29	140.2	3.685
	C1_3		56%	320.3	1.29	96.1	4.539
	C1_4		46%	336.7	1.29	76.6	4.857
Lutron TVE_3	D1_1	G1	100%	390.9	1.54	179.0	Not Tested
	D1_2		84%	376.6	1.50	142.9	
	D1_3		60%	358.6	1.42	97.6	
	D1_4		49%	352.6	1.38	78.3	
Lutron Tuwire_3	D2_1	G1	100%	492.5	1.40	232.7	
	D2_2		68%	445	1.60	143.5	
	D2_3		45%	424.1	1.79	93.4	
	D2_4		36%	416.7	2.00	79.0	
Lutron Hilume_3	D3_1	G1	100%	403.3	1.55	200.2	4.016
	D3_2		77%	380.6	1.47	144.8	3.973
	D3_3		54%	359.1	1.39	94.3	4.044
	D3_4		43%	352.5	1.36	76.9	4.114
Lutron Eco10_3	D4_1	G1	100%	262.5	1.36	165.3	3.481
	D4_2		89%	269.5	1.34	143.6	3.541
	D4_3		62%	285.1	1.32	94.6	3.632
	D4_4		49%	292.2	1.32	74.5	3.664
Tridonic_3	E1_1	G1	100%	274.9	1.41	217.7	3.853
	E1_2		73%	302.4	1.34	146.8	4.891
	E1_3		51%	339.1	1.32	95.6	5.566
	E1_4		41%	355.2	1.31	75.3	5.773
Powerspec_3	F1_1	G1	100%	438.8	1.27	177.0	4.528
	F1_2		84%	428.6	1.24	143.7	4.999
	F1_3		60%	420	1.15	97.3	5.335
	F1_4		48%	417.9	1.11	94.9	5.596

Ballast Trade Name	Ballast No.	Lamp No.	Dimming Level	Filament Current (mA)	Current Crest Factor	Lamp Current (mA)	Filament Voltage (V)
Universal S50_3	A1_1	GL2	100%	274.1	1.30	183.6	3.161
	A1_2		51%	354.7	1.20	83.4	4.678
Universal S30_3	A2_1	GL2	100%	292.3	1.42	182.1	3.242
	A2_2		68%	339.5	1.33	113.0	4.261
	A2_3		33%	388.3	1.40	52.4	5.127
Universal V5_3	A3_1	GL2	100%	403.2	1.35	180.3	3.636
	A3_2		79%	434.5	1.32	134.6	4.354
	A3_3		56%	460.4	1.32	91.1	5.299
	A3_4		44%	471.2	1.31	70.2	5.707
MARK VII_3	B1_1	GL2	100%	308.2	1.29	176.8	3.945
	B1_2		85%	327.8	1.30	142.6	4.233
	B1_3		61%	354.7	1.31	97.9	4.665
	B1_4		46%	372.2	1.33	71.9	4.876
MARK X_3	B2_1	GL2	100%	252.4	1.28	204.6	2.612
	B2_2		75%	287.9	1.34	142.9	3.246
	B2_3		53%	318.1	1.37	95.4	3.726
	B2_4		43%	328.2	1.39	77.9	3.877
Helios-3	C1_1	GL2	100%	246.8	1.32	194.9	2.572
	C1_2		79%	304.1	1.30	143.0	3.483
	C1_3		53%	356.3	1.27	88.3	4.486
	C1_4		47%	365.4	1.28	77.0	4.702
Lutron TVE_3	D1_1	GL2	100%	424	1.53	177.9	Not Tested
	D1_2		80%	406.9	1.47	135.8	
	D1_3		57%	391.5	1.40	92.4	
	D1_4		46%	386.6	1.40	73.7	
Lutron Tuwire_3	D2_1	GL2	100%	534.3	1.40	232.9	
	D2_2		66%	486	1.60	140.1	
	D2_3		45%	472.4	1.85	93.9	
	D2_4		35%	468.5	2.03	76.2	
Lutron Hilume_3	D3_1	GL2	100%	427.2	1.55	200.1	4.013
	D3_2		78%	405.4	1.48	144.3	3.998
	D3_3		54%	386.7	1.39	94.1	4.105
	D3_4		45%	382.3	1.37	77.5	4.177
Lutron Eco10_3	D4_1	GL2	100%	293.6	1.35	155.9	3.62
	D4_2		94%	297	1.34	143.1	3.66
	D4_3		70%	313.3	1.33	93.0	3.813
	D4_4		63%	301.7	1.42	74.7	3.876
Tridonic_3	E1_1	GL2	100%	304.4	1.41	216.8	3.613
	E1_2		75%	337.7	1.33	148.7	4.531
	E1_3		51%	376.1	1.33	93.8	5.339
	E1_4		42%	391	1.30	75.5	5.575
Powerspec_3	F1_1	GL2	100%	485.8	No data	178.6	4.434
	F1_2		84%	466.4	No data	145.4	4.715
	F1_3		57%	430.2	No data	97.7	5.263
	F1_4		47%	444.4	No data	78.6	5.508

Appendix E: Interaction of Daylighting and HVAC Systems

Interaction of Daylighting and HVAC Systems

Peter Morante

July 13, 2004

Sponsored by: Capturing the Daylight Dividend Program

U.S. Department of Energy
New York State Energy Research & Development Authority
California Energy Commission
The Connecticut Light & Power Company
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North Carolina Daylight Consortium
Northwest Energy Efficiency Alliance
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INTERACTION OF DAYLIGHTING AND HVAC SYSTEMS

July 13, 2004

I. Summary

The experiments conducted at the Energy Resource Station, Ankeny, Iowa attempt to determine the interaction between a building's lighting and HVAC systems for a building employing daylighting strategies. The experiments determined there is another building element, windows, that plays an equally important role in energy use and interacts with both the lighting and HVAC systems.

The experiments were conducted from August 22 to September 2, 2003 and from January 27 to February 8, 2004. These dates were chosen to represent summer and winter conditions in both temperature and sun conditions. The summer weather was cooperative with daytime temperatures ranging from mid-70's to 100 degrees and sun conditions ranging from bright sunshine to rain. Winter weather was also cooperative, if somewhat on the cold side. Daily average temperatures ranged from -7^{o}F to 21^{o}F and there were sunny to cloudy days. The experiments measured the HVAC and electric lighting energy used in identical sets of rooms where the only difference were windows. Rooms attempting to maximize the use of daylight to offset electric lighting had windows with visible transmittance (VT) of 73% and solar heat gain coefficient (SHGC) of 0.66 and rooms attempting to minimize solar gain had windows with VT of 23% and SHGC of 0.22. The results are limited by the two short time periods and the use of only two different window systems. Anyone reviewing these results should keep these limits in mind.

The Iowa Energy Resource Station is ideal for conducting experiments to compare the combined use of daylight and HVAC energy. They have two identical sets of rooms facing east, south and west with separate, but identical, HVAC systems. This allows for the testing of different theories in the two sets of rooms.

For the conditions described below and for the two test periods, the set of rooms with higher VT and SHGC window values used less total energy under all weather, solar and time of year conditions. The reductions in lighting energy and, corresponding, reductions in internal heat gain more than offset increased energy needs for cooling caused by increased solar heat gains through the clearer glass windows. Conversely, the increased solar heat gain in the winter assists in reducing heating energy needs. In these test cases, the clearer glass windows resulted in less total energy use than the highly tinted windows. However, there are many window types that were not tested. Different combinations of window glazing, tinting, reflective coatings and shading could have produced greatly different results. There exists a combination of these attributes that would produce optimum energy savings given the location of the building and size of the windows.

Window design and selection is a process of determining building location, orientation, window area, shading and window type. A recently released book, “Window Systems for High-Performance Buildings”, (Carmody, et al, 2004), Chapter 4 discusses, in detail, a window selection process. The book is recommended reading for daylighting designers.

The second objective of the Iowa experiments was to test the installation and commissioning of the self commissioning photo sensor versus today’s commercialized photo sensors. The times required to install the self commissioning photo sensor were about the same as standard sensors. However, the commissioning times were drastically reduced. Based on these results, commercialization of a self commissioning photo sensor is a priority to further the acceptance of daylighting in buildings.

This paper also discusses a different procedure for determining the optimization of energy savings, human comfort, design criteria and cost for daylit buildings given the magnitude of design choices in window systems, lighting controls, building orientation, etc. Return on Investment (ROI) is a well accepted method in financial circles of determining if an investment should be made. The goal is to optimize ROI when making decisions on daylighting designs. To optimize the return of the daylighting investment in windows, lighting, etc., the building owner would continue to invest in these improvements as long as the percentage return continues to increase. Once the next dollar of investment creates a lower percentage return, optimization has been achieved and the owner stops adding daylighting improvements.

II. Objectives

There were two objectives in testing, recording and analyzing data at the Energy Resource Station.

- Determine the interaction between a daylighting strategy for lighting and its effects on the heating and cooling system of a building with regard to energy use.

- Determine the installation and commissioning efforts for the self commissioning photo sensor versus a standard photo sensor.

III. Test Conditions

- A pair of identical rooms facing east, south, and west were used in the experiments. One set of east, south and west rooms, identified as Rooms A, attempted to maximize the use of daylight to offset lighting energy through the use of windows that incorporated visible transmittance of 73% and a relatively high solar heat gain coefficient (SHGC) of 0.66. The other set of rooms, identified as Rooms B, attempted to minimize solar gain and sacrifice some daylighting by incorporating a visible transmittance of 23% and a SHGC of 0.22.

- Both sets of rooms utilized identical lighting dimming systems to capture energy benefits of any daylighting that was present. Continuous dimming was allowed including turning the lights off in the presence of plenty of daylight.
- No north facing rooms were available for this study. The addition of north facing rooms would tend to move the data toward greater energy savings from the use of daylight (clearer glass).
- Day time summer outdoor temperatures ranged from mid-70's to 100 degrees and sky conditions ranged from rainy to bright sunshine. Winter test period temperatures ranged from -10^{o}F to 21^{o}F.
- The lighting energy and interior lighting conditions data are available for each room. However, the HVAC energy data is only available for the sets of Room A and Room B rooms.
- Room Size: 15.5'w x 17.74'd x 8.5'h
  267sqft per room. There are three rooms per set each of the size described here.
- Lighting per room:
  -Fixtures: Four 2x2 lay-in troffers
  -Each fixture contains a dimming electronic ballast and 3 T-8, 31 watt, U-tube lamps
  -The light levels were set to maintain 50 footcandles at a work surface 30 inches off the floor in the center of the room.
  -The lights operated from 7:00-18:00
- Photo Sensors
  - The self commissioning photo sensor developed by the LRC was used in both sets of rooms for the energy testing. These sensors provide continuous dimming including allowing the lights to turn off in the presence of plenty of daylight.
  - For the installation and commissioning time testing the self commissioning photo sensor was compared with two commercially available and commonly used photo sensors.
- Blinds:
  - White horizontal blinds were used in all rooms.
  - East facing rooms – Close blinds so the inner edge is tilted up at a 45 degree angle during the hours 7 AM to noon on sunny or partly cloudy days. Blinds will be down in the horizontal full open position at all other hours.
  - West facing rooms – Close blinds so the inner edge is tilted up at a 45 degree angle during the hours of 1:00 PM and 6 PM on sunny or partly cloudy days. Blinds will be down in the horizontal full open position at all other hours.
  - Southern facing rooms –Blinds will be down in the horizontal position at all hours.
  - Overcast days – Leave blinds in all rooms down in the horizontal position.
- HVAC:
  -Occupied Time: 6:00-17:00
  -Unoccupied Time: 17:00-6:00
  -Room Temperature:
    Occupied Heating setpoint: 70F
    Occupied Cooling setpoint: 75F
    Unoccupied Heating setpoint: 60F

Unoccupied Cooling setpoint: 85F

-Air Flow Rate – Interior:

Occupied Min flow rate: 200 cfm

Occupied Max flow rate: 400 cfm

Unoccupied Min flow rate: 0 cfm

Unoccupied Max flow rate: 400 cfm

-Outside Air – 120 cfm

-Cooling system: The cooling plant consists of a nominal 10 ton air-cooled chiller, rated at 1.14 kW per ton.

- Heating system: A natural gas high efficiency boiler (91% AFUE) is used. The system pumps water to air handlers.

- Internal Heat Gain: A 300 watt electric heater was used to simulate internal gains during the summer test and a 900 watt heater was used during the winter test. No internal latent loads were included.
- Windows (note: The windows are the only items that were different in the two sets of rooms)

	Rooms A	**Rooms B**
Type of Glass	Low-E #3 Insulating ¼” clear, ½” air space, ¼” LOF Pyro Low-E #3	Low-E #2 Insulating ¼” clear, ½” airspace, ¼” VE3-55 #2
Transmittance	Visible Light: 73% Solar Energy: 52% Ultra Violet: 36%	Visible Light: 23% Solar Energy: 14% Ultra Violet: 5%
Reflectance	Visible Light-Exterior: 17% Visible Light-Interior: 16% Solar Energy: 15%	Visible Light-Exterior: 6% Visible Light-Interior:15% Solar Energy: 10%
ASHRAE U-Value	Winter Night Time: 0.33 Summer Daytime: 0.35	Winter Night Time: 0.31 Summer Daytime: 0.33
Shading Coefficient	0.76	0.26
Solar Factor (SHGC)	0.66	0.22
Relative Heat Gain	158 Btu/hr/sq ft	56 Btu/hr/sq ft

- Data Collected

All data collected is recorded at one minute intervals.

Lighting

- Energy use in watts for each room
- Interior lighting levels in footcandles measured on a work surface 30 inches from the floor in the center of the room.

HVAC
- Chilled water entering, leaving and mixed water temperatures for each set of rooms.
- Total gallons per minute entering each set of rooms.
- Chilled water pumping energy (note: constant volume pumps used)
- Outside air volume set points and actual volumes per set of rooms.
- Return and supply air volume set points and actual volumes.
- Return and supply air temperatures.

Room and Weather Conditions
- Outside air temperature
- Outside humidity
- Wind direction and speed
- Barometric pressure
- Solar beam intensity
- Solar normal flux
- Room temperature and humidity

Photo Sensor Testing
- Time to install photo sensors
- Time to commission photo sensors

IV. Results of Daylighting and HVAC System Interaction Tests

Two sets of tests were conducted, one under summer conditions and the other under winter conditions. The summer tests were conducted from August 22, 2003 to September 2, 2003. Winter tests were conducted from January 27, 2004 to February 2, 2004.

All tests were conducted at the Iowa Energy Resource Station, Ankeny, Iowa. Two sets of identical rooms with the exception of windows were used for all tests. The characteristics of these rooms are described above under the Test Conditions section. Room Set A refers to rooms with windows with higher visible transmittance (VT=0.73). These rooms also have higher solar heat gain coefficients (SHGC=0.66). For this report, these rooms are referred to as maximizing daylighting. Room Set B refers to rooms with windows with lower visible transmittance (VT=0.22) and lower SHGC (SHGC=0.22). For this report, these rooms are referred to as minimizing solar heat gain.

A. Summer Test Results

Chart 1: Daily Average Energy Use for Different Sun Conditions (Summer)

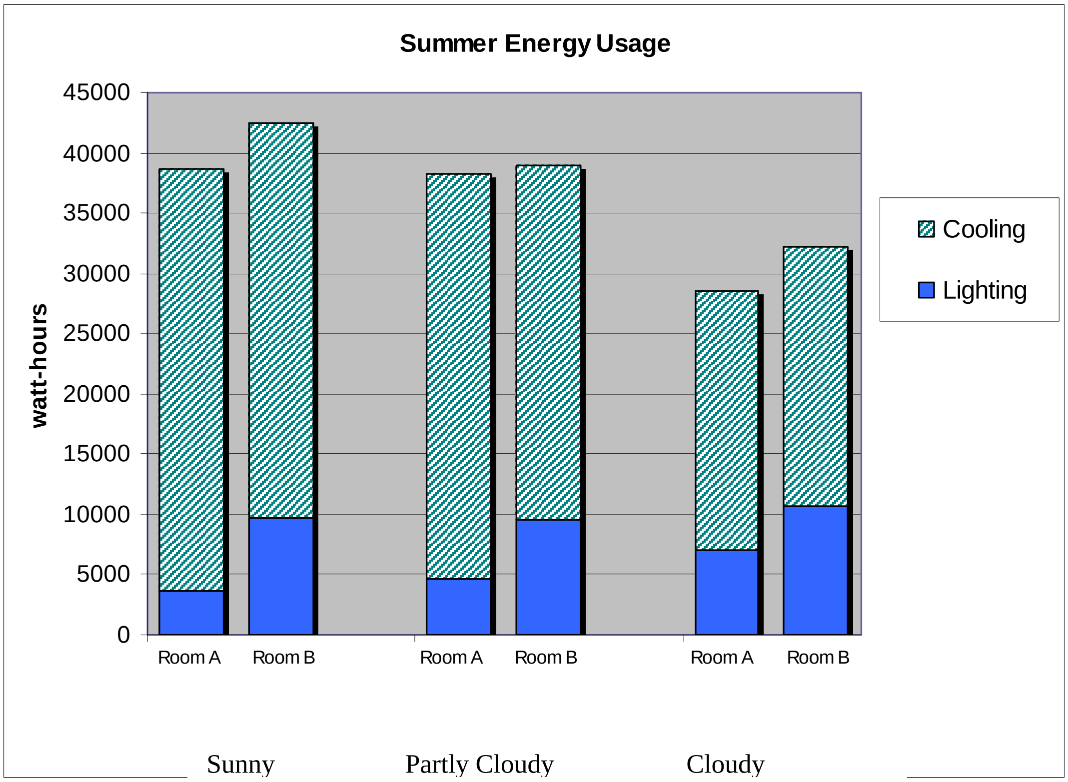
	Maximizing Daylight Case	**Minimizing Solar Gain Case**
Sunny Sky Conditions		
Electric Lighting	3.7 kWh/day	9.8 kWh/day
Cooling Energy	36.6 kWh/day	31.4 kWh/day
Total Energy	40.3 kWh/day	41.2 kWh/day
Partly Cloudy Conditions		
Electric Lighting	4.2 kWh/day	9.7 kWh/day
Cooling Energy	33.8 kWh/day	29.6 kWh/day
Total Energy	38.0 kWh/day	39.3 kWh/day
Cloudy Conditions		
Electric Lighting	7.9 kWh/day	11.1 kWh/day
Cooling Energy	21.5 kWh/day	21.6 kWh/day
Total Energy	29.4 kWh/day	32.7 kWh/day

All the information summarized in Chart 1 above can be found in Appendix A (Quick A-B Comparison) of this report. “A” refers to the set of rooms designated as Rooms A. These rooms contained windows with higher visible transmittance that allowed for greater harvesting of daylight and higher solar heat gain coefficients. The Rooms B had lower visible transmittance and favored lower solar heat gains.

On the chart labeled “Data Summary”, the lighting levels, room temperatures and outside stats are averages for the 24 hour period and include both occupied and unoccupied hours. “Sol-Beam” refers to the solar intensity and is a function of the brightness of the sky. The higher the number the more sunny the condition.

Figure 1 below depicts lighting and cooling energy used during different solar conditions during the summer testing period, sunny, party cloudy and cloudy. These are mean daily values for the three different solar conditions. The energy depicted is for a full 24 hours. The lighting energy savings in the set of rooms with higher VT windows offsets the additional cooling energy needed in these rooms compared to the rooms with lower VT and SHGC.

Figure 1



B. Winter Test Results

Chart 2: Daily Average Energy Use for Different Sun Conditions (Winter)

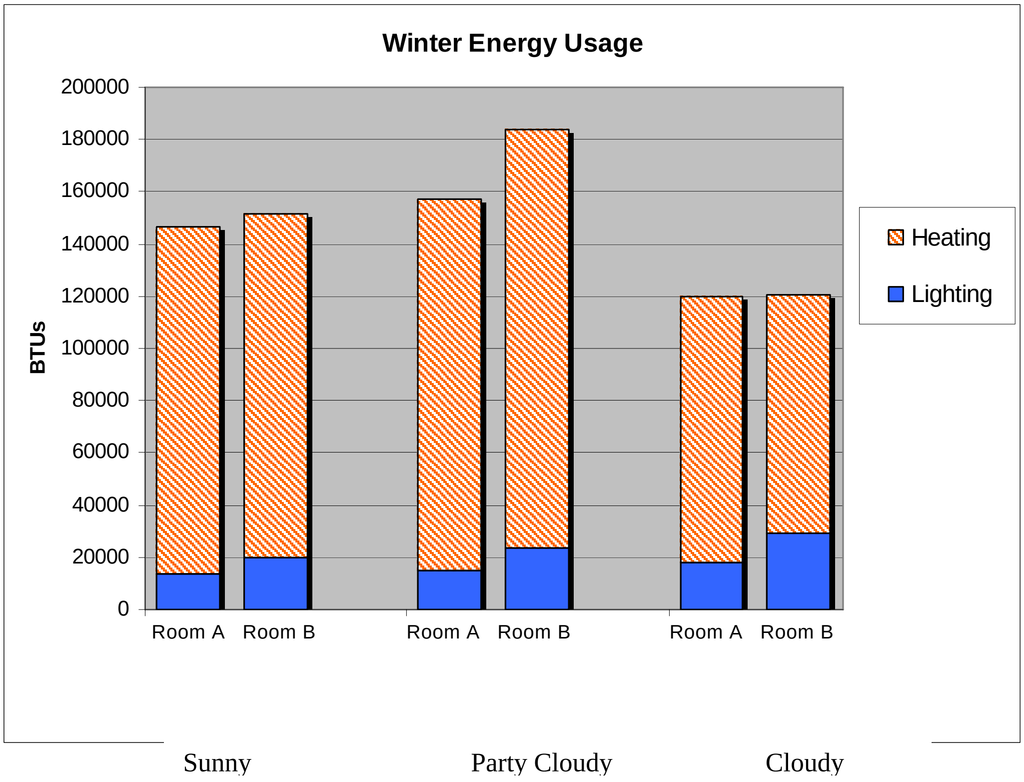
	Maximizing Daylight Case	**Minimizing Solar Gain Case**	**Daily Avg. Temperature**
Sunny Sky Conditions			
Electric Lighting	4.4 kWh/day	6.6 kWh/day	
Heating Energy	127,187 Btu/day	131,761 Btu/day	3.5 ^{o}F
Partly Cloudy Conditions			
Electric Lighting	5.6 kWh/day	7.9 kWh/day	
Heating Energy	135,523 Btu/day	151,415 Btu/day	0.0 ^{o}F
Cloudy Conditions			
Electric Lighting	5.6 kWh/day	9.6 kWh/day	
Heating Energy	102,834 Btu/day	90,294 Btu/day	16.3 ^{o}F

All the information summarized in Chart 2 above can be found in Appendix B (Quick A-B Comparison) of this report. A refers to the set of rooms designated as Rooms A. These rooms contained windows with higher visible transmittance that allowed for greater harvesting of daylight. The Rooms B had lower visible transmittance and favored lower solar heat gains.

On the chart labeled “Data Summary”, the lighting levels, room temperatures and outside stats are averages for the 24 hour period and include both occupied and unoccupied hours. “Sol-Beam” refers to the solar intensity and is a function of the brightness of the sky. The higher the number the more sunny the condition. The “sol-beam” numbers are less than during summer months indicating the sum is much less intense during the winter.

Figure 2 below depicts lighting and heating energy used during different solar conditions during the winterer testing period, sunny, party cloudy and cloudy. These are mean daily values for the three different solar conditions. The energy depicted is for a full 24 hours. Because of the difference in energy units between lighting (watt-hours) and heating (Btu), it was necessary to convert the lighting energy into source Btu’s. Source Btu’s is the amount of energy used at the power plant to produce a kilo-watt hour. To obtain source Btu’s, this report multiplied the lighting kWh by three which indicates the power plant is 33% efficient. It should also be noted the price for a kWh of electricity is about three times more expensive than natural gas on a Btu basis.

Figure 2



C. Data Analysis

Data was only collected for two short periods of approximately ten days each during the summer and winter. Also, only two types of windows were tested. There is a multitude of different window types with differing VT and SHGC than those tested. There is a high likelihood that a different combination of VT and SHGC than the two window types tested would produce lower total energy results.

Lighting Energy Use

- Lighting energy is less in the set of rooms designed with the clearer glass to maximize the daylight contribution regardless of sky conditions or time of year. This is to be expected because of the higher visible transmittance of clear glass.
- On average, approximately 5.3 kilowatt-hours (kWh) per day or approximately 50% of lighting energy was saved in the rooms with greater visible transmittance during the summer test period compared to the rooms with higher degrees of tinting on the windows and 2.8 kWh per day or approximately 35% of lighting energy was saved during the winter test period. Given lower solar angles and shorter periods of sunlight in the winter, a reduction in savings for the winter test period is expected.
- Even on cloudy days, the lighting energy saved was approximately 2 kWh during the summer test and 4 kWh during winter tests in rooms maximizing daylighting (higher VT). On sunny days, the lighting energy saved increased to over 6 kWh during the summer test and was reduced to 2 kWh during sunny winter days.
- South facing rooms saved the most lighting energy. Note: The blind position in south facing rooms was always in the horizontal position. This may account for some of the lighting energy savings compared to the east and west facing rooms whose blinds were tilted for parts of the day.

HVAC Energy

- During the summer tests, on all but the cloudiest days, less cooling energy was used in rooms with less visible transmittance and lower solar heat gain coefficient glass. This glass reduces solar gain, the primary element in cooling needs as determined by conducting an ASHRAE heat gain calculation.
- On average, rooms designed to minimize solar gain (lower SHGC) used 28.0 kWh per day versus 31.9 kWh per day of cooling energy for rooms with windows with greater visible transmittance (higher SHGC). The reductions in internal heat gains caused by the use of less lighting energy in room with higher VT glass did not offset the additional cooling energy requirements caused by higher solar heat gains through the glass.
- Outside temperatures and humidity, solar heat gain through the windows and internal loads determine the amount of heating and cooling required.

- Most of the heating energy is used during unoccupied hours and during morning warm up periods when the heating system is recovering from night time setback temperatures.
- On cloudy winter days, the heating determinants are outside temperature and internal heat gains. Solar heating through the windows is insignificant. The set of rooms with lower VT glass used less heating energy on cloudy days because the lighting load was greater (approximately 13,000 Btu/day less). This additional lighting load provided some of the needed heat.
- On sunny and partly cloudy winter days, the heating energy was less in rooms with higher SHGC. The clearer glass allowed for greater solar heating to offset some of the rooms heating needs. The solar heat gain was also able to offset heating reductions caused by less lighting energy in these rooms (approximately 10,000 Btu/day less).

Total Lighting, Cooling and Heating Energy Use

- It is difficult to compare kilowatt hours for lighting and cooling with Btu of a natural gas for heating. To make this comparison of total energy use, this report uses source energy for electricity (the amount of energy used by the electric generator). Source energy for electricity is approximately three times the energy used at the end use. Therefore the kWh’s are converted to Btu’s of source energy. It is important to note the cost of electricity is also approximately three times that of natural gas.
- On average during the summer and winter test periods, regardless of sky conditions and outside temperature, the total energy used was less in rooms with higher VT windows. The smallest difference occurs during sunny summer days when the average savings for rooms with the higher VT glass was 9,000 Btu/day or about 2%. During these days, solar heat gain through the windows dominates the cooling load. While there is high savings in lighting energy in rooms with higher VT, there is also higher cooling requirements in these rooms. The largest difference occurs during partly cloudy winter days when the average savings for rooms with the higher VT glass was 40,000 Btu/day or about 17%. This occurs because of good savings from the electric lighting and because of the higher solar heat gain through clearer windows.

V. Results of Self-commissioning Photo Sensor Testing

The goal of this part of the experiment was to determine if the self-commissioning photo sensor has a shorter installation and commissioning time than today’s commercially available photo sensors. The LRC’s patented self-commissioning photo sensor was used along with three commercially available photo sensing control systems. Currently the only self-commissioning photo sensor available for testing is the one developed by the LRC.

The photosensors were installed and commissioned in accordance with each manufacturer’s written instructions. The LRC photosensor was installed by LRC personnel and commissioned by Energy Resource Station personnel using instructions written by the LRC. Three different Energy Resource Station personnel installed each the three different commercially available photosensors and commissioned the LRC photosensor and the three commercially available photosensors.

The following data was recorded by Energy Resource Station personnel and reported in a written report to the LRC titled "Photosensor Evaluation, LRC Daylighting Test", September 5, 2003.

Installation

	LRC	**#1**	**#2**	**#3**
Components	Self-commissioning photo sensor; Wall switch	Controller; Photosensor; Wall switch	Photocell	Photoelectric sensor
Group time to review devices, wiring and installation requirements.		**75** x 4 = **300** min.	**30** x 4 = **120** min.	**30** x 4 = **120** min.
Individual time to read and review instructions		**22 + 23 + 20 + 0 = 63** min.	**14 + 15 + 0 + 0 = 29** min.	**10 + 10 + 0 + 0 = 20** min.
Installation time		**37 + 90 +45 + 60 = 232** min.	**5+ 20 + 10 + 45 = 80** min.	**0 + 20 + 10 + 20 = 50** min.
Comments	• Installed by personnel from Lighting Research Center with the assistance of ERS. • Installation time not recorded.	• Sensor terminal too small, has to use a very small screwdriver • Kind of hard to squeeze 3 wires on terminal 4. • More complicated system involving 3 components. Additional time for reading instructions and reviewing installation requirements. • Confusing directions for proper mounting of the light sensor.	• Simple and easy to install, however, the blue and black wires on the sensor caused confusion	• Simple and easy to install • Conflict with mounting recommendations between distance recommendation and light fixture location recommendation. • Not clear as to masking instructions and viewing potential problem area.
Overall installation time		**595** min.	**229** min.	**190** min.

Commissioning

	LRC	**#1**	**#2**	**#3**
Components	Self-commissioning photo sensor and Wall switch	Controller; Photosensor; Wall switch	Photocell	Photoelectric sensor
Commissioning time - day	**5 + 15 + 5 = 25** min. Reference: Note 1	**30 + 15 + 7 = 52** min.		
Commissioning time - night		**5 + 5 + 5 = 15** min.	**23 + 25 + 25 = 73** min.	**8 + 15 + 5 = 28** min.
Comments	• Reference Note 1 • Easy if the detailed instruction are followed • In one room (East A), need to push 'Reset' button 4 times to initiate process, weak transmitter? • White LED is not easy to be seen from far under bright sunny day	• Need both day and night time commissioning • Complicated procedure in measuring/calculating dimming response time • Relatively less time required than that of previous models • Easy to adjust if using typical suggested values	• Trimpot is too small and delicate • Difficult and frustrating to adjust trimpot to meet Setpoint requirement • The sensitivity of the dial was very inconsistent	• Easy. However, the instruction is misleading. "Exceeds" seems should be "is below" according to our experience
Overall commissioning time	**25** min.	**67** min.	**73** min	**28** min

VI. Conclusions

- This was a limited test to determine the interaction of lighting and HVAC systems in a daylighting design. Only two time periods, ten days in August – September, 2003 (summer period) and 13 days in January – February, 2004 (winter period) were used to collect data at Ankeny, Iowa. The variable in the side by side room comparisons were the two different window types. No other window types were tested.
- There is an interaction between the lighting and HVAC systems, as well as the window system in determining the total energy used for buildings employing a daylight design. The interactions based on the data collected and analyzed during this limited test are:
  - The higher the visible transmittance (VT) of the glass the less lighting energy required.
  - The higher the solar heat gain coefficient (SHGC) of the glass the greater the cooling energy required. This is true even though the higher VT and SHGC glass reduced the internal heat gain caused by the electric lighting.
  - Under the summer conditions tested, the total energy required was lower for the rooms with the higher VT and SHGC windows compare to the rooms with lower VT and SHGC windows. The lighting energy saved was greater than the additional cooling energy required in these rooms.
  - Under the winter conditions tested, heating energy is less in rooms with higher VT and SHGC on sunny and partly cloudy days because of the greater solar heat gain through the glass. This is true even though the internal heat gain from the electric lighting system is less because of the use of daylighting.
  - On cloudy winter days tested, the rooms with lower VT use less heating energy because the contribution from solar heat gain and the internal heat gain from the electric lighting system are less.

- For the data periods and window types tested, on average, rooms with higher VT and SGHC used less total energy under all weather, solar, summer and winter conditions. The reductions in lighting energy and, corresponding, reductions in internal heat gain more than offsets increased energy needs for cooling caused by increased solar heat gains through the clearer glass windows.
- Heating energy use is a function of solar heat gain through the windows, internal heat gain and outside temperature. During these tests, less heating energy was used in rooms with higher VT and SHGC glass during sunny and partly cloudy days because of greater solar heat gain through the windows. This solar heat gain more than offset the reduction in heat from the electric lights caused by the use of daylighting.
- There are many types of windows that were not tested. Different combinations of window glazing, tinting, reflective coatings and shading would have produced greatly different results. There exists a combination of these attributes that would produce optimum energy savings given the location of the building and size of the windows.
- The self-commissioning photo sensor represents a marked improvement in commissioning time over most existing photosensor systems. It also does not require nighttime commissioning.

VII.Recommendations

- There are no shortcuts for selecting window systems for a building utilizing a daylighting strategy. The interaction of the window size, tinting, glazing, shading, etc. with that of the building's location (climate) and lighting and HVAC systems make the use of a good building energy simulation program like DOE-2 a necessity. There are too many variables to use rules of thumb to get it right.
- There is no one right answer as to what type of window system is best for all buildings. The purpose of the windows and building design may override any energy criteria. However, once the purpose is defined and a decision is made to utilize daylighting, the designer must recognize the tradeoffs that occur with different window systems. Higher visible transmittance will reduce lighting energy but may cause higher solar heat gains unless some combination of high VT and lower SHGC can be incorporated into the window. A good architectural shading design can also be incorporated into a building's design. Designers need to examine all of the window options available with today's modern window systems and select the best fit to their design criteria.
- Window design and selection is a process. A recently released book, "Window Systems for High-Performance Buildings", (Carmody, et al, 2004), Chapter 4 discusses, in detail, the window selection process. The book suggests a series of sequential questions moving from larger to smaller scale decisions designers should be asking themselves as the building design progresses.
    - Orientation – If climate and building type are known, determine orientation.
    - Daylight Controls – If other conditions are known, determine daylight control strategy.
    - Window Area – If orientation is known, determine window area.

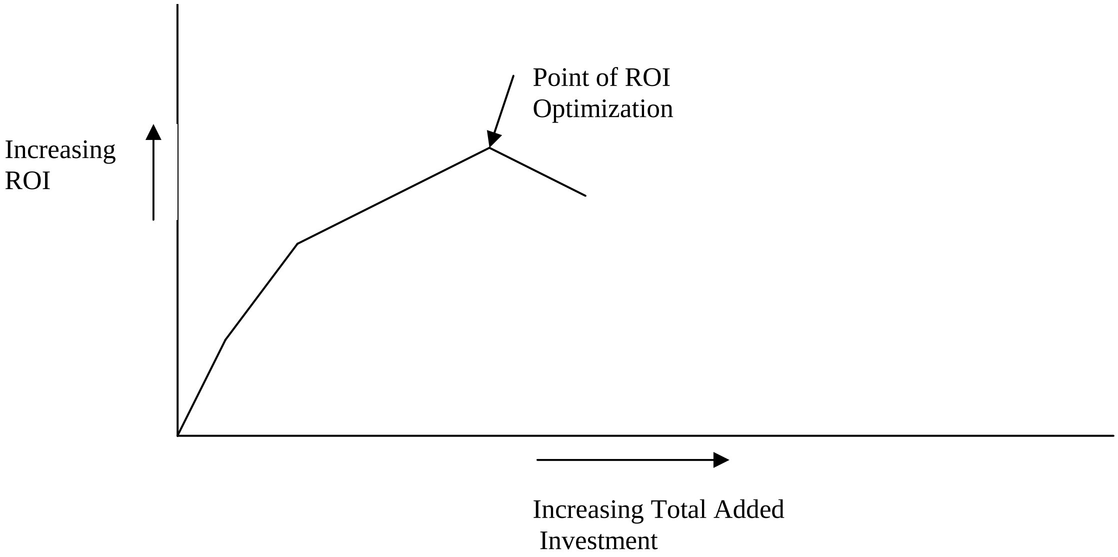
  - Shading Condition – If orientation and area are known, determine shading conditions.
  - Window Type – If other conditions are known, determine window type (glazing, tinting, reflective films).

Note to self: check how to reference this.

- Daylighting needs to be integrated into the building's design and not bid as an option. Bidding it as an option will increase the cost of the daylighting because it becomes impossible to take credits for cost reductions in items like the building's cooling system. Also full integration will ensure optimization of all daylighting components such as lighting controls, windows, HVAC, etc.
- A self commissioning photo sensor must be commercialized to further the acceptance of lighting controls for daylighting. This device overcomes one of the major barriers to the use of daylight. (devices that are easy to install, operate and maintain)
- Optimization for energy savings, human factors, design aesthetics, cost, etc. are possible and have been discussed in many referenced books and articles on windows and daylighting. One method of optimization that is not discussed at length is optimizing the return on the investment for daylighting, better windows, etc. It is this return on investment that may have the most meaning to the building's owner and should be further developed as a means of promoting daylighting.

  Return on Investment (ROI) is defined as net income as a proportion of net book value of the investment. ROI is usually express as a percent return on the investment. To utilize the ROI criteria for daylighting buildings requires some modifications to the basic ROI definition. Net income becomes net savings from the total added investment. Net book value becomes the total of the net added investments in the daylighting design including lighting controls, window changes and modifications to the building's mechanical systems (HVAC). To optimize the return of the daylighting investment in windows, lighting, etc., the building owner would continue to invest in these improvements as long as the percentage return continues to increase. Once the next dollar of investment creates a lower percentage return, optimization has been achieved and the owner stops adding daylighting improvements. Figure 3 depicts this process. An example is also provided to demonstrate how this criteria of optimizing ROI works for daylighting strategies.

Figure 3



Example of Optimizing ROI for Daylighting Strategies:

Cost and saving dollars within this example are illustrative only. They do not represent actual costs to install the suggested measures. The saving potential is also illustrative only.

Assumption: The building owner and designer have committed to a daylighting strategy. The initial window design calls for double glazing with a u value of 0.5, visible transmittance of 0.7 and solar heat gain coefficient of 0.6.

The building owner and designer want to know what they can add to the design to improve the return on investment. The measures added and the order they are added are illustrative only. They do demonstrate the objective of optimizing the ROI.

Measure 1:
Add continuous dimming to the lighting system.
Net cost = cost of the dimming controls ($125,000) less reductions in cooling equipment ($25,000) = $100,000
Net annual savings = lighting energy savings because of dimming and daylight ($10,000) plus reduced cooling energy, less internal load ($5,000) = $15,000
ROI = Total Net Savings/ Total Net Cost = $15,000/$100,000 = 15%
Install the dimming

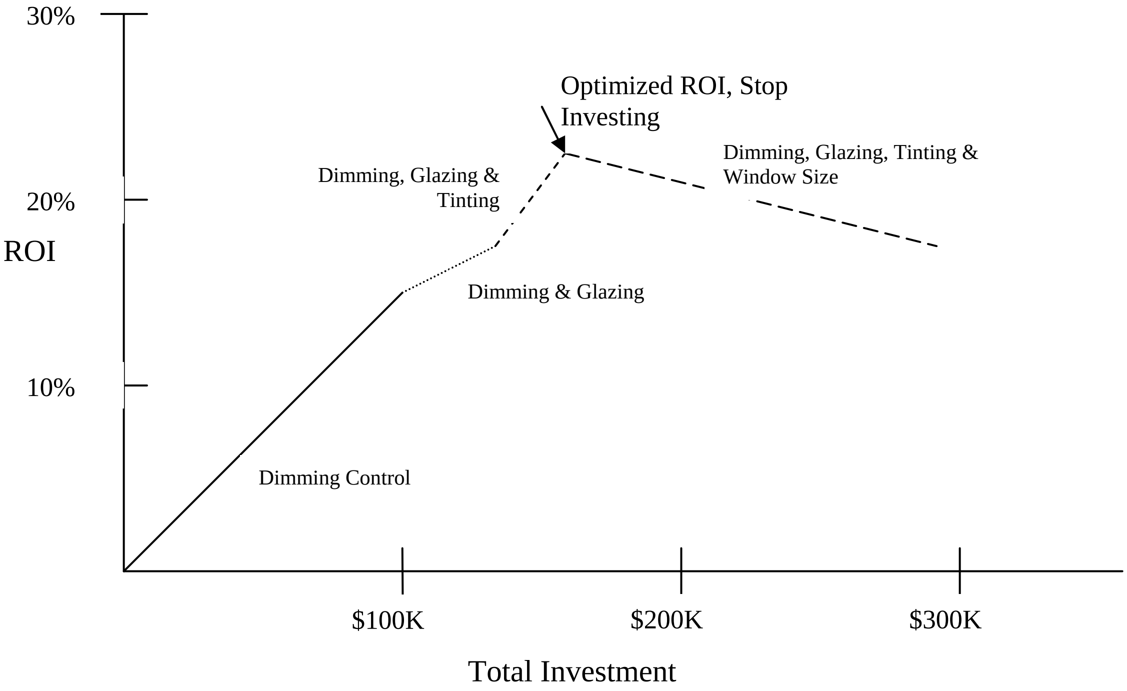
Measure 2:
Change windows to triple glazing decreasing u factor to 0.3

Net added cost of additional glazing is $50,000 less further reduction in heating and cooling equipment ($15,000) = Total added cost of $35,000
Net added annual savings = Reduction in cooling and heating costs = $10,000
Total net additional cost = $100,000 (dimming controls) plus $35,000 (glazing) = $135,000
Total net annual savings = $15,000 (dimming controls) plus $10,000 (glazing) = $25,000
ROI = Total Net Savings/ Total Net Cost = $25,000/$130,000 = 18.5%
ROI increased over measure 1 alone, Install glazing and dimming controls

Measure 3:
Add tinting to windows to decrease SHGC to 0.4
Net added cost of tinting is $25,000 less further reduction in cooling equipment ($10,000) plus added cost for heating equipment ($5,000) = Total added cost of $20,000
Net added annual savings = Reduction in cooling costs = $10,000
Total net additional cost = $100,000 (dimming controls) plus $35,000 (glazing) plus $20,000 (tinting) = $155,000
Total net annual savings = $15,000 (dimming controls) plus $10,000 (glazing) plus $10,000 (tinting) = $35,000
ROI = Total Net Savings/ Total Net Cost = $35,000/$155,000 = 22.5%
ROI increased over measure 1 and 2 together, Install tinting, glazing and dimming controls

Measure 4:
Increase the size of the windows to 60% of wall area for aesthetics and daylighting
Net added cost of increasing window size is $100,000 less reduction in lighting equipment ($10,000) plus added cost for heating and cooling equipment ($50,000) = Total added cost of $140,000
Net added annual savings = Reduction in lighting costs of $50,000 less increase in heating and cooling costs ($30,000) = $20,000
Total net additional cost = $100,000 (dimming controls) plus $35,000 (glazing) plus $20,000 (tinting) plus $140,000 (larger windows) = $295,000
Total net annual savings = $15,000 (dimming controls) plus $10,000 (glazing) plus $10,000 (tinting) plus $20,000 (larger windows) = $55,000
ROI = Total Net Savings/ Total Net Cost = $55,000/$295,000 = 18.6%

ROI decreased over measure 1, 2 and 3 together, Install tinting, glazing and dimming controls but do not install larger windows.


30%
20%
10%
ROI
Optimized ROI, Stop Investing
Dimming, Glazing & Tinting
Dimming, Glazing, Tinting & Window Size
Dimming & Glazing
Dimming Control
$100K
$200K
$300K
Total Investment

Appendix F: Daylighting Controls Practicum Curriculum Outline

Introduction

In order to achieve the energy savings associated with effective daylighting design, people need to understand how best to use the new, more effective electric lighting controls for daylighting that are currently being developed by manufacturers. They also need to know how to get the most out of existing hardware. The *Daylighting Controls Institute* will be designed to give specifiers and facility managers the hands-on education they need to optimize energy-savings through the effective use of daylighting control systems, while maintaining the satisfaction of building occupants.

Curriculum Goal

To train a range of lighting decision makers to successfully select, specify, install, commission, and use a system that will effectively control electric lighting in response to available daylight while maintaining the satisfaction of building occupants.

Curriculum Objectives

Participants completing the *Daylighting Controls Institute* will be able to

- Review and evaluate daylighting control products from a range of manufacturers to select the ones that will work most effectively in their application.
- Develop a design and specification for optimal energy savings and occupant satisfaction.
- Properly install, or supervise the installation of, the selected daylighting control system to assure effective operation.
- Successfully commission the selected daylighting control system to assure maximum energy savings, proper system operation over time, and building occupant satisfaction.
- Check the system operation during the commissioning process to recognize whether or not it is installed correctly and take the steps necessary to correct any problems with the system’s operation.
- Recognize when an installed system is not operating effectively, determine the problems with the system, and re-commission the system to restore proper operation.

Curriculum Outline

It is expected that the one-day *Daylighting Controls Institute* will be structured in accordance with the following outline.

1. **Introduction of presenters, participants, and topics –**Each training session will begin with the introduction of the presenters and information on their qualifications. Each participant will be asked to introduce him or her self, briefly describe his or her background, and provide a brief statement on

what he or she hopes to be able to do following the training. The presenters will record these last statements on a flip chart. These will be used at the end of the training to assess to if participants' needs were met. These statements will also help to guide presenters on what information to emphasize during the training. Presenters will then review the schedule for the day.

2. **Demonstration and overview of an effective daylighting control system** – Using the daylight commissioning crate, control system components, and measurement tools provided in the curriculum kit, presenters will demonstrate an effective daylighting control system. The presenters will demonstrate only one model system, however, they will present information on several system options. The presentation will include

- Only "stand-alone" systems not integrated into any type of building automation system
- Both open and closed loop systems
- Only systems currently available on the market.

The objectives of this exercise are to

- Give participants an overview of what they should be looking for when specifying a system that will control electric lighting in response to available daylight
- Give participants an idea of some effective systems and products currently on the market
- Demonstrate and explain what is meant by "effective" operation
- Introduce participants to the various components of the system
- Provide an overview of the steps involved in selecting, specifying, installing, and commissioning a system effectively.

In this demonstration session presenters will

- Show and describe each system component, explain its operation, explain the integration of the various system components, and explain how these component interact to operate the system
- Demonstrate system operation in response to a variety of daylighting conditions and measure various parameters of the system's operation (e.g., control signal levels, wattage reduction, illuminance levels, sensor readings, etc.)
- Provide an overview presentation of several available, effective daylighting control systems/products

3. **Selecting daylighting control system components** – Using the daylighting control products included in the curriculum kit and other presentation aids, the presenters will train participants to evaluate daylighting control products.

The objectives of this session are to

- Demonstrate the features of each product and explain how these features contribute to the product's effective operation
- Teach participants to critically evaluate product features

- Teach participants to evaluate the conditions in the space for which the system is being selected and assess how these conditions will affect which product should be selected for that space
- Review the questions that participants need to ask manufacturers' representatives or distributors to be able to select a product to meet their needs
- Introduce participants to a "decision tree" that provides a step-by-step process for selecting daylighting control system components to meet the needs of a particular application

In this session presenters will

- Show each product, describe its features, review the literature that accompanies the product, allow participants to experiment with each product, either in the model room, or an actual room
- Review each product feature/operating parameter in a graphical presentation to explain how each feature/operating parameter relates to how the product will operate once installed or how each feature effects its installation, commission, or operation
- Present and review a short list of questions that participants should ask manufacturers in order to critically assess a product they are unfamiliar with and compare its operation to other available products
- Demonstrate the use of this questioning procedure using the products in the kit
- Present and review the "decision tree" that provides a step-by-step process for reviewing the needs of a particular application and selecting a product to meet the needs of that application
- Present two application examples and have participants use the decision tree process to select among the products provided in the kit for each application.

4. **Developing a successful daylighting control system design specification** – Presenters will review the information that needs to be included in a system specification and the steps involved in developing the specification.

The objectives of this session are to

- Teach participants how to develop a design specification for a daylighting control system for a particular application
- Review the information that needs to be included in a successful specification
- Teach participants to evaluate a specification to assess whether or not it meets the requirements of the application

In this session presenter will

- Show two examples of successful daylighting control system specifications, explain each part of the specification and the information included, explain why this information is needed

- Review the process involved in assessing the environmental (spatial) conditions in an application and developing a specification based on those needs
- Break the participants into small groups of 3 to 4 each, give each group a space (pictures, drawings, write-up of spatial conditions, etc.) and have them develop a specification using the products included in the curriculum kit (one space will be the room in which the training is taking place)
- Once the specification exercise is complete, have each group review their space with the class and present their design specifications for the space
- Have the group that developed the specification for the room in which the training is being held, mock-up the system they designed in the room using components available in the kit
- If there is sufficient time and equipment have each group also install their designs in the space simultaneously
- Have the class predict how successful the installations will be based on the mock ups.

5. **Commissioning a daylighting control system** – Presenters will review the importance of proper system commissioning, the steps involved in the commissioning process, and have participants practice how to commission a sample system and assess the success of the commissioning process.

The objectives of this session are to

- Help participants to recognize the importance of proper commissioning to effective system operation
- Teach participants the steps involved in the commissioning process and have them practice these steps
- Instruct participants how to assess if the commissioning process has been successful and how to troubleshoot any problems identified in the post commissioning assessment
- Recognize product features that impact ease of commissioning.

In this session presenters will

- Review the steps involved in the commissioning process in a presentation format, explain how to perform each step and why each step is important to the process
- Demonstrate the commissioning steps using the equipment provided in the curriculum kit, have participants try the commissioning procedures using the sample products
- Ask a group other than the one that installed each of the mock-ups of the daylighting control systems in the training room to commission a system
- Have a different group measure the system's operation both before and after the commissioning using the measurement tools available in the curriculum kit

- Demonstrate how each system operates differently based on the system's design and operating characteristics, explain how this needs to be taken into account during commissioning
- Record the before and after measurements, discuss the results with the class, ask the class if each system was successfully commissioned
- Review the steps involved during the assessment phase of the commissioning process (how to determine if a system is operating effectively) and use this assessment process to systematically determine the operation of each system that was mocked-up in the training room
- Explain how to troubleshoot any problems that might be encountered in the assessment in an interactive discussion with the class.

6. **Conclusions, tips, and review of lessons learned** – The presenters will review the material presented and the list of learning objectives provided by participants at the beginning of the day and present conclusions.

The objectives of this session are to

- Review and reinforce the material presented with participants
- Assess participants grasp of the information
- Provide additional information where needed
- Help participants to apply the information to their own situations
- Conclude the training.

In this session presenters will

- Present a review of major content points and discuss these with the class
- Ask participants questions about each section being reviewed to see if they have an understanding of the information and can apply it to a "real world" situation
- Re-present material as needed if participants cannot respond to questions appropriately
- Review the list of learning objectives that were recorded on the flip chart in the morning
- Ask each participant how the information provided in the training will help them to meet the objective they identified at the beginning of the day
- Give the participants lists of resources where they can find additional information on daylighting controls (e.g., Daylight Dividends website, etc.)
- Explain that the training will be updated as new products come on the market and tell participants how they can keep in touch with the program to get these updated trainings

Conclude session and pass out evaluation forms to participants.