PNNL-13536

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

New Technology Demonstration Program

Results of an Attempted Field Test of Full-Spectrum Polarized Lighting in a Mail Processing/Office Space

E. E. Richman

June 2001

Prepared for the U.S. Department of Energy
Federal Energy Management Program
under Contract DE-AC06-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

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Preface

The mission of the U.S. Department of Energy's Federal Energy Management Program (FEMP) is to reduce the cost of government by advancing energy efficiency, water conservation, and the use of solar and other renewable technologies. This is accomplished by creating partnerships, leveraging resources, transferring technology, and providing training and technical guidance and assistance to agencies. Each of these activities is directly related to achieving requirements set forth in the Energy Policy Act of 1992 and the goals that have been established in Executive Order 13123 (June 1999), but also those that are inherent in sound management of Federal financial and personnel resources.

The Pacific Northwest National Laboratory (PNNL)[a] supports the FEMP mission in all activity areas. This responsibility includes working with various Federal energy managers to identify, monitor, and evaluate the performance of new energy efficiency technologies suitable for installation at Federal sites.

This report provides the results of a field evaluation that PNNL conducted for FEMP under the New Technology Demonstration Program. The report examines the performance of a full-spectrum polarized lighting system installed in a small test area in the mail processing room at the U.S. Postal Service headquarters building in Washington, D.C. Participating in this effort were the U.S. Postal Service, Daniel Karpen (professional engineer and private consultant), Clearvision Inc., and PNNL. The lighting equipment was provided by Clearvision and installed by the U.S. Postal Service Facilities Department. PNNL monitored the technology's installation process and the operating performance of the lighting system.

(a) Pacific Northwest National Laboratory is operated by Battelle for the U.S. Department of Energy under contract DE-AC06-76RL01830.

Summary

The understanding of the physics of light, the physiology of the human reaction to light, various study datasets, and specific laboratory tests have been instrumental in defining, proving, and promoting the potential benefits of both full-spectrum and polarized light. These data and knowledge have led to the hypothesis that the use of full-spectrum polarized lighting in the work environment can lead to more efficient visual acuity at lower overall light levels, which in turn leads to reduced lighting energy use. A "real-world" test demonstration of this hypothesis was undertaken under the Department of Energy's (DOE) Federal Energy Management Program (FEMP) New Technology Demonstration Program (NTDP). The test demonstration involved cooperation from the technology proponent (Daniel Karpen), Clearvision Inc., a Federal test site (United States Postal Service headquarters building in Washington, D.C.), and an analysis laboratory (Pacific Northwest National Laboratory).

A Cooperative Research and Development Agreement (CRADA) was used as the format for this cooperative multi-organization project. The CRADA document identified responsibilities and activities in the project as well as a test methodology and project plan agreed to by all parties. The test protocol developed for this project was a comparison of the perceived ability of the occupants to perform their tasks under two different lighting systems and at different horizontal light levels. The general lighting levels in horizontal foot-candles (fc) that the occupants were comfortable with and that they believed provided adequate lighting for their tasks would form the basis for determining potential energy savings. Any difference in the chosen levels for both systems could be considered potential energy savings (fewer lumens of light required for same performance = fewer watts of power needed).

The first part of the testing was a baseline phase where the comfort and effectiveness of the current typical Federal-type lighting was evaluated through real-world occupant responses to varying light levels (three different levels). After the baseline tests were complete, new full-spectrum lamps and polarizing diffusers were installed and arrangements were made to begin the second half of the test. Several delays in beginning the second half of the test due to space remodeling and procurement of materials allowed the occupants to become familiar with the new lighting at typical office-type lighting levels for approximately 6 weeks after a several-month delay without any test activities. Just prior to beginning the second half of the test, the test-space occupants chose not to continue with the testing activities. The primary reason offered was general occupant dissatisfaction with the light and concerns from the USPS administration of potential problems associated with these employee concerns. Efforts were made to understand and ally any concerns through discussions with the affected employee's immediate supervisor and two supervisory levels above. A quick survey for the employees themselves was also prepared and offered in an effort to understand the actual concerns. This survey was never

provided to the employees, but conversations with each of the supervisors provided a summary of the employee concerns. The basic concern was that the new lighting had a dimmer look to it. There were also some complaints related to more difficulty in seeing with the new lighting. Some specific concerns such as a desire for task lighting were noted by the Facility Department Supervisor as being old existing concerns that had nothing to do with the testing of new lighting.

Because of the halt in the test project, it was not possible to collect the critical data regarding occupant reactions to the technology and their capabilities while working under it. Therefore, no analysis could be completed and no results could be determined from the testing. The inability to complete the test does not provide any concrete information about the applicability or effectiveness of the polarized lighting itself.

Contents

Introduction

An assessment of the potential energy savings associated with the use of full-spectrum polarized lighting in a work space was initiated as part of the Department of Energy's (DOE's) Federal Energy Management Program (FEMP) New Technology Demonstration Program (NTDP) in 1997. This project was intended to provide information on the effectiveness and application of this technology that could help Federal energy managers and other interested individuals determine if this technology had benefits for their occupied spaces. The use of an actual mail processing/office work area provided the capability of evaluating the technology's effectiveness in the "real world."

The report begins with some brief background on full-spectrum lighting and polarized light technology and its reported benefits followed by a description of the actual field test setup and planned administration of the test. This includes a basic assessment of the data that was collected and any pertinent results from it. The remainder of the report is devoted to a discussion of the general evaluation strategy that was developed specifically for this test. An appendix is included with copies of the documents and forms used in the collection of survey data and a summary of the actual response data.

Technology Background

Full-spectrum polarized lighting is the combination of full-spectrum lighting and the polarization of that light. Full-spectrum lamps produce light in a spectrum (wavelengths) that are near that of natural daylight. Polarized light reduces glare by selectively polarizing the light so that it does not reflect directly off surfaces. This combination is said to provide a better seeing environment including full, truer colors and reduced glare that can provide better contrast and, therefore, better visual acuity.

By increasing the quality of the spectrum of lighting and reducing glare on work surfaces, many believe that lower lighting levels are sufficient to perform the same task that requires a higher level with standard lighting. This effect has been shown to be true in certain laboratory tests in certain set conditions. This effectiveness of polarization on reduced glare has also been shown to depend greatly on the angle of view from the source of light. Laboratory tests have also shown that in specific conditions, lighting levels can be reduced when the light is polarized without affecting the occupant's ability to see effectively. These laboratory test results provide the basis for an assertion that polarized lighting can be used to reduce lighting levels, and therefore energy use, in the workplace.[a]

The technology proponent, Daniel Karpen, P. E., offers the following background information and perspective:

> *Visibility is related to the amount of light present, measured in foot-candles. But other fundamental characteristics concerning vision, task, visibility and lighting are of equal or greater importance. "Seeing" is not related to the number of foot-candles per se. Rather, it is mostly a function of the luminance, or brightness, of the task detail and its contrast with the background. Luminance is dependent on task detail reflectance – how much light reaching a task is absorbed by it and re-reflected, so it can be seen.*
>
> *The other factor, contrast, is the difference in task brightness between the task detail and its background. Gray printing on lighter gray paper can be difficult to see, while black print on white paper is much easier to see. Contrast is important to seeing.*
>
> *The nature of light and the lighting system can affect both the brightness of the task detail and its contrast. For example, a magazine or book placed on a table under a light source located slightly to its front appears to have "washed out" print detail. Observed from the*

(a) "Multilayer Polarized Light," Technical Memorandum (TM-4), Illuminating Engineering Society of North America, August 1997.

side, the print appears darker. Changing the point of view with respect to the light source significantly increases the contrast of the print to the background.

In the first instance, light bouncing off the task reduces contrast due to reflected glare, also called veiling reflections. In the second instance, reflected glare goes off in directions other than to the eye, so it does not wash out contrast between the task detail and background.

The portion of light rays causing reflected glare or veiling reflections is known as "horizontally" polarized. The light's "vertically" polarized portion penetrates into the task instead of bouncing off the surface and returns to the eye carrying information about the task, detail and color. Illuminating an object with light from which the horizontally polarized portion has been reduced yields greater contrast and better perception of detail and color.

Multilayer polarized diffusers convert horizontally polarized light rays emitted from a light source to vertically polarized light. As a result, reflections are reduced and visual contrasts are enhanced significantly. If contrast is improved, the amount of lighting needed for equivalent visual performance is reduced.

By improving the quality of the light source, and by reducing glare, lower lighting levels are sufficient to perform tasks. Tens of millions of square feet of multi-layer polarizing diffusers were manufactured and installed in fluorescent lighting systems from 1960 to 2000, mostly in conjunction with cool-white or warm-white fluorescent lamps. The effecttiveness of the use of polarizing illumination in reducing glare has been proven both in the laboratory and in actual use. By using polarized illumination, as a general rule of thumb, one can cut the lighting levels in half. Most of these installations were outside the Federal government. None of the installations used full-spectrum lamps.

The purpose of this new technology demonstration project was to demonstrate and evaluate the combination of full-spectrum lighting with polarizing diffusers in a real-world working environment in the Federal sector.

Full-spectrum polarized lighting combines full-spectrum lamps with a polarizing diffuser to provide illumination matching the spectral energy distribution and polarization characteristics of natural daylight. The definition of a full-spectrum lamp is a lamp that has a color rendering index of 90 or above and correlated color temperature of 5,000 K or above, and may provide some ultraviolet light. Claims have been made for health benefits, but these claims are not the subject of the study.

It is now fairly well established through the work of Sam Berman[(a)] that the raw foot-candle output of a light source, as measured by the photopic light meter, does not relate to the ability of one to see, especially when comparing different light sources. Sam Berman's work clearly showed that the use of the scotopic light output of a lamp more closely approached the actual ability of one to see. Recently, Navvab[(b)] has extended Sam Berman's work to suggest that raw foot-candles on the working surface are not as important as the overall lighting scheme in a space, as he showed that the fully lit surround lighting condition improved visual acuity.

The early work of Marks,[(c)] published in a seminal paper in 1959, suggested that visual acuity could be improved by the use of polarized lighting. Vertically polarized lighting produces less glare than horizontally polarized light, which scatters off surfaces without refraction. The work of Marks was extended by Blackwell[(d)] in a series of papers over a 25-year period.

In 1989, Karpen suggested that by combining full-spectrum fluorescent lamps with polarizing diffusers, one could reproduce daylight in a space and save significant amounts of energy. Karpen had installed about 30 of these full-spectrum polarized lighting systems mostly in institutional settings on Long Island and elsewhere and published a number of papers[(e)] on his work. Karpen showed this technology cut the use of electricity by 70 to 85 percent with payback periods of 3 to 7 years for Long Island locations served by the former Long Island Lighting Company, now the Long Island Power Authority.

(a) Berman, S., D. Jewett, B. Benson, T. Law, "Despite Different Wall Colors Vertical Scotopic Iluminance Predicts Pupil Size," *Journal of the Illuminating Engineering Society of North America*, IESNA, Summer 1997, pp. 59-68.
(b) Navvab, M., "A Comparison of Visual Performance Under High and Low Color Temperature Fluorescent Lamps," *IESNA 2000 Annual Conference Proceedings*, August 2000, pp. 359-366.
(c) Marks, A. M., "Multiyear Polarizers and Their Application to General Polarized Lighting," *Illuminating Engineering*, Vol. 54, February 1959, pp. 123-135.
(d) Blackwell, H. R., "Evaluating the Visual Significance of Reflected Glare, Utilizing Visual Performance Data," *Illuminating Engineering*, Vol. 58, No. 4, April 1963.
Blackwell, H. R., "Discovery of Substantial Error in Current ESI Values for Lighting Applications Involving Polarized Light," *Lighting Design and Application*, May 1978, pp. 44-47.
Blackwell, H. R., "Final Report—A Study of Visual Effectiveness of Polarized Light," Ohio State University Institute for Research in Vision, November 1984.
(e) Karpen, D., "Progress in Full-Spectrum Polarized Lighting Systems," *Energy Engineering*, Vol. 92, No. 6, 1995, pp. 18-48.
Karpen, D., "Designing Efficient Full-Spectrum Polarized Lighting Systems for the Electronic Office," *Proceedings of the 12th World Energy Engineering Congress*, Atlanta, Georgia, October 24-27, 1989, pp. 553-558.
Karpen, D., "Designing Efficient Full-Spectrum Polarized Lighting Systems for General Interior Lighting," *Proceedings of 13th World Energy Engineering Congress*, October 9-12, 1990, pp. 563-574.
Karpen, D., "Full-Spectrum Polarized Lighting Recreates Daylight," *Consulting-Specifying Engineer*, April 1994, pp. 42-48.

Field Test Setup

The assessment test was located in a mail processing area in the United States Postal Service (USPS) headquarters building in Washington, D.C. The area was chosen because the occupants spend the majority of their day under the lighting in the area and have no access to daylight. This serves to restrict their access to “other” lighting systems that could effect the results of the test. The occupants are engaged in typical mail processing/office-type work and the surroundings are typical of Federal office environments. Dimmable electronic T8 ballasts and controls were installed in the fixtures in the space to facilitate the periodic adjustment of light level.

Test Procedure

The first 9 weeks of testing involve the existing T-8 electronic ballast standard USPS design lighting without polarizing lenses. Throughout these first 9 weeks, the level of the existing lighting was changed each week, either up or down according to a prescribed evaluation protocol by means of the dimming control. Each of three prescribed lighting levels was visited three times during the 9 weeks according to the following schedule:

	Week								
	1	2	3	4	5	6	7	8	9
Existing Lighting Levels	high	mid	low	mid	low	high	low	mid	high

This schedule ensures that each lighting level is visited three separate times and not always from the same direction (e.g., from a higher or a lower lighting level). The schedule incorporates a high to low set, a low to high set, a one level up and down set and a two level up and down set. This arrangement conforms to the statistically based Latin square design that is used to control effects due to the order of exposure to the various conditions (in this case lighting levels).

	Test #1	Test #2	Test #3
Week 1-3	Light level “high”	Light level “medium”	Light level “low”
Week 4-6	Light level “medium”	Light level “low”	Light level “high”
Week 5-9	Light level “low”	Light level “high”	Light level “medium”

The lighting is initially set at a “high” level consistent with current typical lighting practice (around 50 footcandles on the work surface). The “low” value was determined to be approximately 20 footcandles based on the light level typically designed for use by the Technology proponent (Kahn). The “mid” value was set midway between the high and low. The changes in lighting level were made between Friday after hours and Monday start of workday. This provided the occupants with an entire weekend away from the workplace lighting between changes. This provides the best opportunity to allow for occupant evaluation of lighting on its own merits without direct, near-term comparison of previous lighting.

At the end of this 9-week evaluation period, multilayer polarizing lenses were installed in each of the fixtures. For the next 9 weeks the lighting levels was to be changed in a manner identical to that used in the first 9 weeks. The entire 18-week evaluation period should appear to the occupants to be one continuous consistent evaluation with as little as possible knowledge of lighting system changes.

The occupants in the evaluation area were surveyed once each week on or about Wednesday to allow them to become accustomed to that week's lighting. Weeks that incorporated a holiday or other major work schedule disruption were considered off-weeks. The lighting level for off-weeks was set the same as the previous week. However, the survey was administered in the same manner for that week.

The occupants were told that they are part of a study being conducted on occupant responses to lighting conditions in real-life settings. They were told that changes would be made periodically in the lighting system so that their response and assessment of it could be recorded. They were not told any details of the project such as when changes would be made and specifically what type of lighting is being installed. They were, however, given some minimal instruction at the start of the test as to what attributes of the lighting in their space we wanted them to be aware of.

Illumination measurements (for reference only) were taken at each workstation for each of the three proposed lighting levels. This allowed direct association of survey data with more precise lighting level conditions.

Survey Administration

The initial letter with data survey and the weekly response surveys were administered by USPS staff. One to two weeks prior to the start of the test, the initial survey and letter were distributed to each room occupant. The surveys were returned by the occupants directly to PNNL's Richland, Washington, office for processing. Names or other personal identifying information were not used on any of the survey responses. Each survey provided a blank for the last four digits of the occupant's Social Security Number (SSN) to be used in comparing the results of each occupant individually. This method allows the tracking of individual data from week to week. It does not, however, allow the identification of the individual to the data because only the researcher has these four digits (surveys are sent directly to the researcher through U.S.

mail, not handled by the employer) and the researcher has no knowledge of the occupant's complete SSN. The inclusion of these four digits was, of course, voluntary and did not have to be provided if the occupant still had concerns about anonymity.

Survey Format

The survey instrument is the primary data-collection portion of this evaluation. An initial characterization survey was administered prior to the test periods along with a letter describing the test project. This survey provided information on the kinds of work performed and visual concerns of the occupants. The weekly survey is designed to collect occupants perceptions of how the lighting (that week) affects how they see with respect to their ability to comfortable and effectively do their work. The PNNL description letter, initial characterization survey, and weekly response survey are included in the Appendix.

General Evaluation Strategy

Major Issues

The combination of full-spectrum lamps and polarization of light creates a more complicated situation in terms of evaluating effects. Since both full-spectrum light and polarization do exist as stand-alone technologies, the lighting community may be interested in the specific benefits attributable to each alone.

The assessment of lighting systems by human users is by nature very visually oriented. Humans naturally associate light level differences with visual ability (sundown—loss of exterior visibility). Therefore, a natural tendency of lighting users will be to initially assess lower light levels as less visually effective.

There is some level of light that must be maintained for an acceptable level of visual ability. The reported effects of full-spectrum polarized light indicated that much less light can be used effectively. However, the current lighting levels applied to buildings are subject to variation (factors of 2 and more) and therefore make the definition of a base lighting level (upon which comparison and energy savings are based) difficult. In addition, the level of light considered appropriate with full-spectrum polarized light must be chosen to achieve maximum energy savings without being considered a failure by the occupants providing their assessment.

Since this is a field evaluation and not a laboratory test, the conditions of environment, occupants, and activities cannot be strictly controlled.

The full-spectrum polarized light technology can save money by decreasing the levels of light needed and therefore reducing the power required to light a facility. To assess and quantify these potential savings with respect to use in Federal facilities, the methodology must:

- Determine the applicability of the full-spectrum light system (at a level that is cost-effective compared to standard lighting) to ensure it provides lighting that is functionally equivalent to existing lighting systems and is acceptable to typical occupants as workplace lighting.

- Determine typical potential savings associated with the application of an appropriate full-spectrum polarized light system and compare life-cycle costs with other lighting systems.

To accomplish this in a field setting, the evaluation must focus on occupant perception, comfort, and acceptance of the lighting system. Unlike laboratory assessments where occupants evaluate specific tasks under controlled conditions, this evaluation must be able to reasonably determine occupant satisfaction and effects on work environments.

Because of the natural tendency of humans to instantly perceive general light levels directly related to visual ability, a method must be used to mitigate this effect. Occupants must therefore be able to work in a normal fashion surrounded by one lighting system (existing or full-spectrum polarized lighting). This will help ensure that their opinions are based on their activity and reactions to the lighting system itself without constant comparison with a higher or lower level system nearby. Occupants must exist in this near 100% control or full-spectrum polarized lighting for a long enough period to allow them to become accustomed to and accept or reject the system on its own merits. This will be very difficult if occupants must travel through other differently lighted areas to and from or during work. Therefore, the space(s) chosen must be such that there is minimal contact with other lighting.

The primary evaluation tool must be occupant perceptions and reactions to various levels of full-spectrum polarized lighting and standard lighting systems. The evaluation can be strengthened by attempting to determine occupant perceptions of functionality of specific tasks (reading, writing, screen viewing, etc.). Other potential effects of changing lighting systems such as fatigue and eye strain must also be considered. Overall perceptions such as general visual enhancement should also be determined as part of a complete assessment of occupant reaction to the lighting system. This evaluation will be performed via an occupant survey or query. This query may be administered by mail or as an on-line query through existing computer systems if these are present in the evaluation areas.

Evaluation Parameters

- *level* - light levels for control area(s) and the full-spectrum polarized lighting area(s) must be set and documented as a measure of the relative light levels between technologies and as compared with current industry practice.

- *occupant acceptance* - this will need to be carefully measured over a long enough period of time to mitigate initial natural occupant perceptions and comparisons with other lighting systems. Fairly large numbers of subject occupants must also be used to ensure a reasonable sampling of occupant reactions.

- *Energy differences* - long-term metering is not required for this type of lighting evaluation. One-time measurements of operating fixtures as well as other manufacturers and independent test data and fixture counts will provide the needed energy consumption data.

- *Operational differences* - information on costs, maintenance, lifetime, etc. will be needed to calculate cost-effectiveness of the technology. Most of this will be available from manufacturers data and Federal site experience.

Experimental Design

Two independent variables have been determined to potentially affect user performance, behavior and job satisfaction. Each independent variable will be manipulated to determine its effect on user performance, behavior, and job satisfaction. The independent variables are lighting type (standard T8 lighting and full-spectrum polarized lighting) and lighting level (high, medium, and low). The dependent variables for this study generally fall under the categories of visual effectiveness and visual satisfaction. Measures for this study will be a seven-point, self-evaluation questionnaire filled out by subjects during each of the testing periods.

The questions the subjects will be responding to cover brightness, reflections, glare, physical discomfort associated with the eye, suitability of the light for the tasks they perform, etc. A complete survey with the questions is attached.

To make an effective comparison between lighting levels and type of light, each subject will be exposed to each light level under both types of light. An absolute judgment of visual effectiveness and visual satisfaction for the different lighting conditions is not required to determine which design is best for each subject. A relative measure is appropriate and will be obtained by applying a "within groups" format to the study. All levels of independent variables are combined with every level of every other independent variable. Many extraneous variables exist that could confound the study and should be addressed or measured to ensure valid results. These variables include age, glasses/contacts, sickness, use of task lighting, background contrast and lighting distribution, type of task (e.g., computer, reading), number of breaks from workstation, length of shift.

Subjects

From a statistical view, the following formula (Snedecor and Cochran, Statistical Methods, 7th, 1980) provides a method of estimating the sample number of observations required to achieve significant results based on an estimated error variance and standard deviation.

$$n = \frac{(Z_{a/2})^2 (o)^2}{E^2}$$

where:
- n = required sample size
- $Z_{a/2}$ = the desired confidence level of the resulting sample size (1.65 for 90% confidence)
- o = the estimated standard deviation variation in the entire sample based on the term 0.21*h for a skewed distribution where h is the maximum value of difference in the sample data. The survey questions had responses from 1(good) to 7(bad). Therefore the variation and resulting standard deviation value is 0.21*(7-1) or 1.26.
- E = the error vale of the responses. This was chosen at 0.5 to represent a fairly tight distribution of responses around the expected value.

To achieve statistical power at 90% confidence level, at least n=18 subjects are needed.

Test Progression and Results

The project initially began with interest from the Pentagon Building in Washington, D.C., in providing real-world testing spaces. Several meetings were held at the site and specific rooms were identified. However, delays in obtaining the full-spectrum polarizing fixtures for installation and the ongoing major renovation efforts and associated schedule conflicts forced the Pentagon to decline participation. A search for another test site resulted in a CRADA agreement with the USPS headquarters building, also in Washington, D.C. A mail processing area was chosen as a test space and the first nine weeks of the test with standard efficient office type lighting (no polarizing lenses) began as planned. The USPS contact made the lighting level changes (low = 35 footcandle [fc], mid = 42 fc, High = 50 fc) and distributed the surveys each week.

At the end of the first half of the test, the fixtures in the test space were to be retrofitted with polarizing lenses and full-spectrum lamps. However, the polarizing lenses that were ordered and delivered for the test were not the size needed to fit safely in the existing fixtures. This caused a delay of several months as different types of retrofits were considered, and finally new diffusers had to be ordered, fabricated, and shipped to the test site. The retrofit was completed with polarizing diffusers and 36-watt Sylvania "Luxline-Plus" full-spectrum lamps. This retrofit lighting remained in the test space at the high level of 50 fc for approximately 6 weeks without any testing activity. During this time several occupants in the space raised concerns about the lighting. The operating services manager relayed these concerns and indicated that they would not be able to continue with the test since their primary concern necessarily had to be the working environment of the USPS employees. The summary of the concerns relayed by the supervisor was general occupant dissatisfaction with the light and concerns from the USPS administration of potential problems associated with these employee concerns. The most specific concerns relayed were the dimness of the new lighting, difficulty seeing, and a desire for task lights.

The technology proponent, Daniel Karpen, P. E., offers the following additional background information:

> *Mr. Karpen visited the site in response to these complaints. Mr. Karpen has had experience in diagnosing electromagnetic field problems from fluorescent ballasts.*[a] *Mr. Karpen felt that the installation of a 36-watt lamp into a ballast designed for 32-watt lamps was causing electromagnetic field problems. Mr. Karpen had specified a full-spectrum 32-watt lamp be employed in the test; however, a 36-watt lamp was substituted in place of the 32-watt lamps. Mr. Karpen suggested that the 36-watt lamps be removed and a compatible 32-watt fluorescent lamp be installed in place of the 36-watt lamps, as the earlier 3500 K, 32-watt fluorescent lamps did not have any problems because they were compatible with the 32-watt ballasts. Unfortunately, the test was discontinued before the full-spectrum 32-watt lamps could be obtained to replace the incompatible 36-watt lamps.*

Efforts were made to understand and ally any concerns through discussions with the affected employee's immediate supervisor and two supervisory levels above. A quick survey for the employees themselves was also prepared and offered in an effort to understand the actual concerns. This survey was never provided to the employees but conversations with each of the supervisors confirmed the previous summary of the employee concerns. The head of the facility department did relate that the desire on some employee's part for task lighting was an old existing concern that had nothing to do with the testing of new lighting. He also spoke with the employees directly in an attempt to determine a way to correct any conditions to continue with the testing but determined that this was not possible and terminated the testing. Within a week the fixtures in the test space were returned to the original standard lighting.

(a) Karpen, D., "Electromagnetic Fields from Fluorescent Ballasts Solved by Shielding," *Energy Engineering*, Vol. 94, No. 4, 1997, pp. 7-16.

Because of this halt in the test project, it was not possible to collect the critical data regarding occupant reactions to the technology and their capabilities while working under it. Therefore no analysis could be completed and no results could be determined from the testing. The inability to complete the test does not provide any concrete information about the applicability or effecttiveness of the polarized lighting itself. The occupant perception that the polarized lighting system was generally dimmer is a known attribute of the technology because of the manner in which polarization orients lighting away from side areas and towards task areas. It is the opinion of the author that this phenomenon and the fact that the occupants were aware that this was a test of "new" lighting were the primary drivers in the discontinuation of the test demonstration.

Because there is essentially no survey data from the second half of the test, it is not possible to present any comparisons between the two lighting systems. Because this was the ultimate goal of the test project, there are no actual reportable results. However, the data from the first half of the testing was analyzed to determine if any effects associated with the changing of light levels with the standard lighting were noticeable.

A 95% confidence level (F-test at 0.05) of statistical significance was applied to the responses to the questions for the three different light levels averaged over the three test weeks for each level. None of the responses to the 17 questions produced any **perceivable** preference for higher or lower light levels from the occupants. This may be due in part to the low sample size of typically only 6 to 9 respondents in each week rendered any trend in responses signifcantly insignificant. This could also be a result of other environmental or life activity factors that by themselves tended to overshadow any effects due to lighting level alone. It is impossible with this specific test protocol to determine the exact causes of these specific results. However, these data do suggest that the small difference between light levels (7.5 fc) used in this test may have been imperceptible compared to other changes with time in environment.

Appendix

Initial Study Letter to Occupants
Initial Characterization Survey
Weekly Response Survey

August 6, 1999

Dear USPS Staff Member,

The room you work in has been selected as a trial space for lighting systems under consideration for use in USPS and other Federal facilities. These systems are going to be evaluated for USPS/DOE by Pacific Northwest National Laboratory (PNNL).

Over a 22 week period the lighting in your workspace will be adjusted or replaced several times by USPS facilities staff and you will be asked to give your candid evaluation of how effective, comfortable, and useful the lighting is to you. The changes will be made with minimal disturbance and as much as possible during off-work hours and you may not be aware of what or when the change has been made.

Approximately each Wednesday or Thursday during the test period we will ask you to respond to a one-page survey (approximately 2-3 minutes to complete). We ask that you complete the survey while seated in your normal work position under typical work conditions.

We also ask that you provide the last 4 digits of your SSN on the survey (no names!) and return it directly to PNNL in the prepaid, pre-addressed envelope provided. **This ensures that neither PNNL, nor the USPS can associate your responses to you**. PNNL is committed to reporting responses generically without any connection to specific individuals.

We appreciate your willingness to evaluate various lighting systems and provide us your candid input. You are, of course, free to choose at any time whether or not to provide us with responses to our surveys. If you have any questions about this activity please contact Richard Hawkins or Paul Fennewald of the USPS or myself at PNNL.

Thank you,

Eric Richman
Pacific Northwest National Laboratory
Box 999 K5-16
Richland, WA 99352
(509) 375-3655 eric.richman@pnl.gov

Lighting Test Background Information Last four digits of SSN __ __ __ __

Age group: ___ less than 40 ___ 40-55 ___ greater than 55

Sex: ___ M ___ F

At work do you normally wear:

___ Contacts?

___ Eyeglasses?

___ Reading Glasses?

To your knowledge are you colorblind/color deficient? ___ Y ___ N

Do you have cataracts or other impairments that currently effect your vision? __Y __N

How much of your typical workday (hours) involves:	Less Than 1 Hour	1 to 4 Hours	More Than 4 hours
computer word processing?			
computer data input and analysis?			
reading print on white paper?			
reading print on glossy paper (i.e., magazines, brochures)?			
looking at small print or objects with fine details?			

Do you have any problems or concerns about your current workplace lighting?

When completed please return in the attached prepaid preaddressed envelope. Thank you for your input!

Lighting Survey ID Number (last 4 digits of SSN): ___________

Today's Date: _____________ Time: _____________

Please answer the following questions based on how you feel about the overhead lighting in your workspace **this week**. Please use the following 7-point scale to indicate your level of agreement with each of the statements below by circling **ONE** of the seven numbers next to each statement.

Disagree Very Strongly	Disagree Fairly Strongly	Disagree	Undecided	Agree	Agree Fairly Strongly	Agree Very Strongly
1	**2**	**3**	**4**	**5**	**6**	**7**

1 2 3 4 5 6 7 -- This lighting allows me to see comfortably.

1 2 3 4 5 6 7 -- Under this lighting I experience difficulty reading my computer screen.

1 2 3 4 5 6 7 -- The overhead lighting is too bright for me.

1 2 3 4 5 6 7 -- Under this lighting reading printed materials is difficult.

1 2 3 4 5 6 7 -- I am using my task lighting (undershelf lights) for longer periods of time.

1 2 3 4 5 6 7 -- This overhead lighting is acceptable for the work I do.

1 2 3 4 5 6 7 -- My eyes tire more easily at work than usual.

1 2 3 4 5 6 7 -- I find printed materials are easy to read with this lighting.

1 2 3 4 5 6 7 -- This overhead lighting is insufficient for the tasks that I perform.

1 2 3 4 5 6 7 -- Under this lighting, reading glossy materials (magazines, brochures) is difficult.

1 2 3 4 5 6 7 -- This lighting is pleasant to work under.

1 2 3 4 5 6 7 -- This lighting makes colors in the room appear natural.

Please use the following 7-point scale to indicate how easy or difficult it is to read each of the four sentences below by circling **ONE** of the seven numbers next to each statement.

Unable To Read						Very Easy To Read
1	**2**	**3**	**4**	**5**	**6**	**7**

1 2 3 4 5 6 7 -- While other plants put the sun's energy to work, the fungus must look elsewhere.

1 2 3 4 5 6 7 -- The end result of this project will be a sky atlas that includes 1,870 photographs of celestial bodies and their statistics.

1 2 3 4 5 6 7 -- Whenever you see a pile of leaves turning to compost, you are watching a fungus eating. The fungus has become the earth's scavenger.

1 2 3 4 5 6 7 -- Sky Survey astronomers have made scores of important discoveries including the fact that our universe is probably twice as old as previously believed. The Sky Survey indicates that the universe is probably more than 4 billion years old.

- Overall, how do rate the current overhead lighting from 1-(unacceptable) to 7-(great). _____________
- Comments?

When completed please place in USPS mail in the attached prepaid and addressed envelope. Thank You!

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