APPENDIX 4.2 – A

DRAFT REPORT: ENERGY SAVINGS FOR LOAD-SHEDDING BALLAST FOR FLUORESCENT LIGHTING SYSTEMS

Sponsored by: Connecticut Light and Power

Prepared by: Yukio Akashi, Ph.D.

Jason Neches

Andy Bierman, MS

1. Introduction

Load shedding ballasts could be used as an effective means of load management by reducing the peak demand for electricity needed for lighting. This is especially true for the brief and infrequent times when demand for electricity approaches the capacity of the power supply system and prices soar as more expensive means of generation an/or transmission are called upon to meet the demand. Lighting offers the opportunity to reduce demand without impacting productivity and normal business activities by dimming to lower power levels. Thereby, lighting is still provided to preserve function, but at a reduced level. However, before such a load-shed technique is applied to the real world, it is important to understand occupants' light level requirements with respect to dimming.

A recent study at the Lighting Research Center (LRC) investigated a detectable range of illuminance change and suggested that occupants could not detect up to 20 % illuminance reduction regardless of initial illuminance or dimming speed within the experimental conditions (Kryszczuk, 2001). A similar study, in which the subjects were more sensitive to illuminance change than in Kryszczuk's study, also suggested that illuminance could be changed by up to 20 % from the initial value without being detected by occupants when they were devoted to tasks (Shikakura, 2001).

However, it is unknown what cues occupants use to detect illuminance change and whether the reducible illuminance range defined in the above studies, up to 20 % change from the initial illuminance, could be extended if slower dimming speeds or smoother dimming functions are employed. To detect such illuminance changes, two cues—memory of the initial illuminance and the transient change in illuminance—are likely decision factors. Sensitivity to the transient illuminance change occurring over time periods shorter than around 3 seconds has already been well investigated by a series of studies on flicker (e.g. Kelly, 1961, 1971). Longer, more drawn out illuminance changes occurring over many seconds, as could easily be done for load shed, has not been investigated as completely. The first experiment of this study seeks to determine if memory of initial illuminance levels is the main clue to detecting dimmed light levels. If so, then less effort could be placed on investigating different dimming rates and functions and more effort focused on determining the appropriate ultimate dim level. With regard to the above question of whether using slower dimming speed and or smoother dimming functions can extend the reducible illuminance range, this study focused on the effects of dimming functions rather than that of very slow dimming speed. This is because fast dimming speed, or short dimming periods that are presumably less than 15 seconds, allow the use of less expensive dimming techniques than long dimming periods, and very long dimming periods, such as hours in length, would not be responsive enough for load shed.

Knowing what people can detect in terms of illuminance reduction is the first step in understanding what occupants' dimming requirements are. Beyond detection, and perhaps more relevant to load shed dimming, is determining what level of dimming is acceptable to occupants. Acceptable dim levels must be at least as low as what is a detectable change in illuminance, and quite possibly they are much lower depending on the context, thereby enabling a greater load shed potential. Since acceptability may vary according to motivation to energy savings, this study also investigated the effects of subjects' bias on acceptable dimming range.

2. Objectives

To aid in specifying the dimming parameters of load shedding ballasts, the following objectives were defined:

- To investigate the mechanism of how occupants detect illuminance changes: *memory study*
- To investigate the effect of different dimming functions on detectable and acceptable dimming ranges: *dimming curve study*
- To investigate the effect of motivation on the acceptable dimming range: *bias study*.

3. Literature survey

Recently, the LRC had conducted an experiment on the detection of dimming (Kryszczuk, 2001). The experiment measured when subjects perceived a reduction in luminance on a target and its surroundings under different conditions of initial illuminance, dimming speed, and task context. While conducting a task, each subject signaled the detection of illuminance reduction, as soon as the subject noticed it, by pressing a manual switch. The time necessary for the subject to detect the illuminance change was recorded from which the amount of illuminance reduction was calculated. The results suggested that regardless of the initial illuminance, dimming speed (ranging from 3.7 to 340 lux per second), and task context, the illuminance could be reduced by up to 22% without being noticed by subjects.

Another recent study conducted similar experiments (Shikakura et al., 2001). The study tackled the same question of to what degree illuminance could be reduced without detection by occupants under different initial illuminance levels, target illuminance levels, and dimming speeds. The results of the experiment suggested:

- When subjects conducted no tasks, 50 % of the subjects could not notice an illuminance change of up to 7 %, regardless of the initial illuminance and dimming speed. The subjects hired in Shikakura's experiment seemed more sensitive to illuminance change than subjects in the LRC experiment, or the particular conditions in the experiment heightened their sensitivity.
- When conducting a visual search task or VDT task, or when being interviewed, 50 % of the subjects could not notice the illuminance change by up to 20 % from the initial level.

These studies imply that lighting levels may be reduced by about 20 % without compromising occupant satisfaction with the lighting because such a change would barely be detectible. However, these studies do not deal with occupants' acceptance of possibly greater illuminance change, or the effects of dimming curve functions and occupants' motivation to energy conservation on acceptability. To investigate these factors, the following three experiments were carried out.

4. Experiments

In this study, three experiments—*memory study*, *dimming curve study*, and *bias study*—were conducted. The *memory study* addressed the question of whether one can memorize the initial illuminance level and how long this memory is sustained. The *dimming curve study* investigated the effects of dimming function on detectability and acceptability of illuminance reduction. The *bias study* addressed the question of how occupants' motivation influences the acceptability of illuminance reduction. All three experiments used the following experimental setup:

4.1 Experimental setup

The experiments used a windowless private office and an adjacent room. Figure 1 shows the private office viewed from the adjacent room. Although, in this picture the door is open, the door remained closed during the experiment. Figure 2 illustrates the plan of the private office and the experimental system in the adjacent room. The interior wall and ceiling of the private office was painted white (reflectance: 85%). The reflectance of the floor carpet was about 30 %. The office was furnished with a bookshelf, a desk and a chair. The office was equipped with three-direct/indirect pendant luminaires suspended from the ceiling. Figure 3 shows the ceiling with the luminaires and the luminous intensity distribution of the luminaires. The experimental apparatus in Figure 2 was composed of the above described luminaires with dimming ballasts and T8 fluorescent lamps; an operating system—a desktop computer, a picoammeter, a photo-sensor, and a DC power supply; a communication system—two telephone sets and a "hands-free" phone tool; and a monitoring system—a TV monitor, a digital video camera with a transmitter, and a receiver. Table 1 summarizes the details of the experimental system.

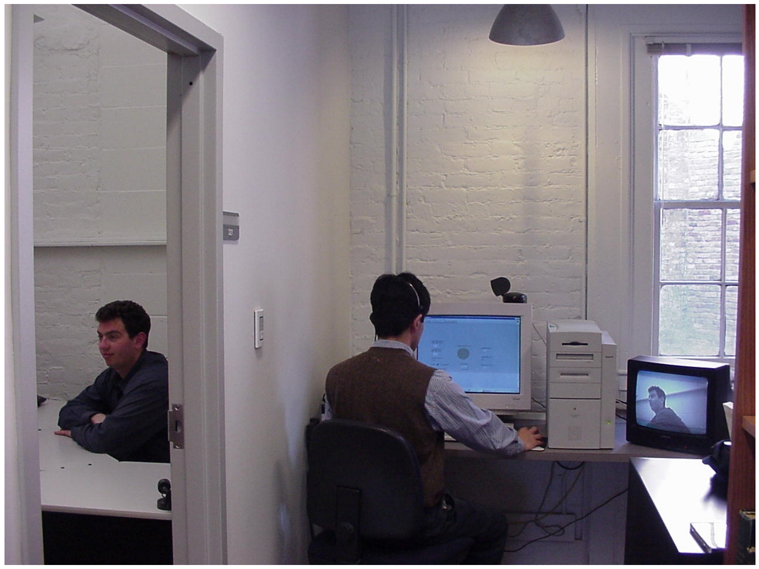


Figure 1. Windowless private office and adjacent room used in all three experiments

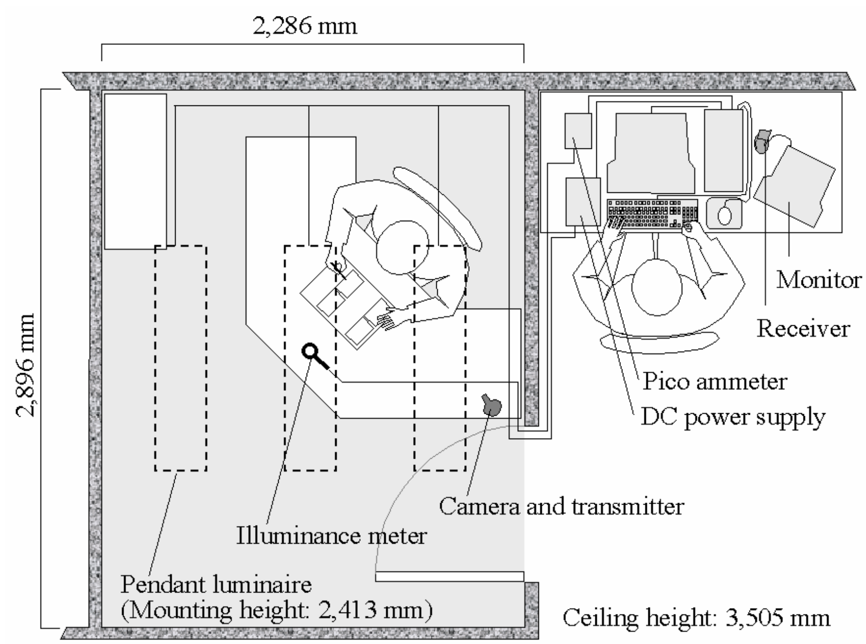


Figure 2. Room plan and experimental setup

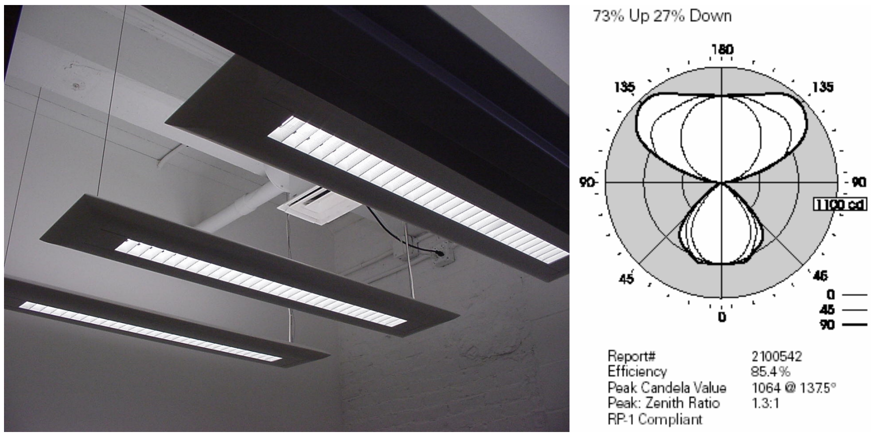


Figure 3. Direct/indirect pendant luminaires (Crescent, Ledalite)

Table 1. Experimental system.

Components	Product name	Manufacturer
3 Luminaires	Crescent (8316T02PN)	Ledalite
3 Ballasts	M2-PD-T8-5C-B-120 Gold Edition Programmed Start, dimming 5 ~ 110%	Motorola
6 Fluorescent lamps	FO32/835/XP	Osram Sylvania Inc.
1 Computer	P5-166	Gateway
1 Picoammeter	485 Auto ranging Picoammeter	Keithley
Software	Lab View 6.0	National Instruments
1 DC power supply	E3632A	Hewlett Packard
1 Photo sensor	268P photopic, cosine response	Graseby Optronics
1 Color TV monitor (13”)	PC1342	CRAIG
1 Camera and transmitter	XC10A	X10, Inc.
1 Receiver	VR30A	X10, Inc.
2 Telephones	DX2NA-12CTXH TEL (BK)	Nitsuko America Co.
1 Hands-free phone tool	Vista, M12	Plantronics

4.2 Memory study

The *memory study* investigated whether subjects could memorize the initial illuminance level and how long the memory of the subjects was sustained.

4.2.1 Experimental conditions

Table 2 summarizes the experimental conditions employed in the *memory study*. As independent variables, the target illuminance and eye closure time varied. The initial illuminance was constant at 500 lx. The dependent variable of the experiment was subjective evaluation of whether the illuminance at a given moment is different from the initial illuminance. The three target illuminance levels that are higher than the initial illuminance (500 lx) were used as balancing conditions.

Table 2. *Experimental conditions.*

Variables	Range
Target illuminance (lx)	976, 781, 625, 500, 400, 320, 256
Eye closure period (seconds)	3, 100

4.2.3 Experimental procedure

Twelve subjects, ranging from 22 to 41 years of age, participated in the experiment. An experimenter escorted a subject to the private office and seated the subject in the chair. The subject was exposed to the initial illuminance of 500 lx, for about five minutes so that he/she would adapt to this lighting condition. During this adaptation time, the subject read and signed an informed consent form. The experimenter gave instructions about the experimental procedure to the subject. Then, the experiment began. First, the subject closed his/her eyes for a given period, 3 or 100 seconds. When closing their eyes, the subject used an eye mask to prevent light from coming through their eyelids. While the subject sat with his/her eyes closed, the experimenter changed the initial illuminance level to one of the target illuminance levels. Second, the experimenter asked the subject to open his/her eyes and answer whether the illuminance level was changed from the initial illuminance level. The subject was allowed to choose one from three choices—“down”, “same” or “up”. The orders of the target illuminance and the eye closure time were randomized across subjects. All 14 (7×2) conditions were repeated three times for each subject.

4.2.4 Experimental results

For each of the 14 experimental conditions, all 36 responses (three answers from each of the twelve subjects) were analyzed. Figure 4 shows the percentage of subjects who responded "down" for the 14 conditions. Figure 4 suggests:

- Subjects are able to memorize the brightness under the initial illuminance and can reliably detect reductions greater than 20%.
- As eye closure time increases, memory may fade and therefore the sensitivity to illuminance change may decrease. This is based on the sensitivity to reduction after the 3-second eye closure being higher than that after the 100-second eye closure. For instance, the comparison between the 100- and 3-second eye closure periods at 50% probability, when 50% of the subjects detected illuminance changes, suggests that illuminance reduction by up to 20% and 30 % of the initial illuminance was undetectable respectively.

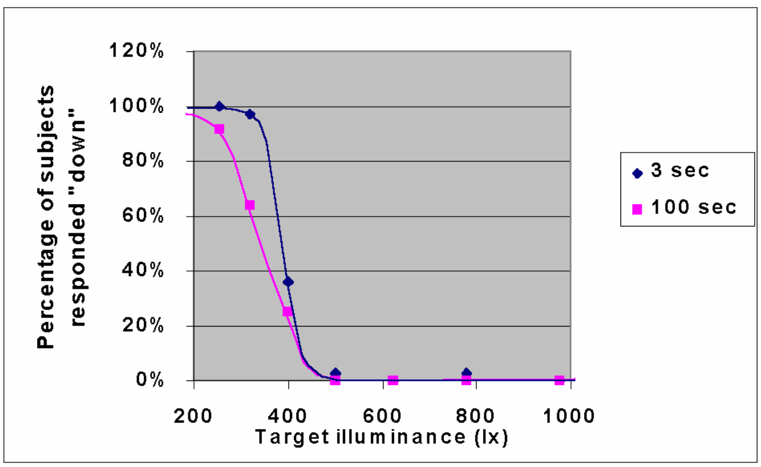


Figure 4. Percentage of subjects who responded "down".

A two-factor analysis of variance (ANOVA) with replication was conducted using all the subject data. Table 3 shows the results of the ANOVA. Table 3 shows that the ANOVA found significant differences between different target illuminance levels and between eye closure period conditions, and in their interaction. These statistical results supported all the above suggestions derived from Figure 4.

***Table 3.** Two-factor analysis of variance with replication.*

Source of Variation	SS	df	MS	F	P-value	F_{crit}
Target illuminance	24.78571	6	4.130952	184.1984	1.29E-67	2.157911
Eye closure period	0.291667	1	0.291667	13.00536	0.000419	3.902557
Interaction	0.5	6	0.083333	3.715818	0.001769	2.157911
Within	3.453704	154	0.022427			
Total	29.03108	167				

4.2.5. Discussion:

The results of the memory experiment support the hypothesis that people can detect changes of illuminance greater than about 20% based solely on memory of the initial light level. Therefore, over the range of times tested, the actual dimming speed, or function, presumably has little effect on detecting illuminance reductions.

The data also suggest that subjects could remember the initial illuminance more precisely after the 3-second eye closure period than after the 100-second eye closure. This implies that as eye closure time increases, the memory of the initial illuminance fades. However, an experimental confound, dark adaptation, might have influenced the sensitivity of subjects to illuminance changes. Some of the subjects reported that all the illuminance presentations looked brighter after the 100-second eye closure than those after the 3-second eye closure. This might be because the 100-second period allowed the subjects time to adapt to the dark condition of covering their eyes, while less adaptation occurred for the 3-second period. This confound, which proved very difficult to eliminate from this type of experiment, works to make decreases in illuminance less detectable over longer periods of time. Therefore, we cannot conclude at this point whether the further decreases in illuminance for the same level of detection result from the adaptation confound or from some other effect over time. Nevertheless, for the time periods tested, 3 and 100 seconds, we can put a limit on the additional amount of dimming possibly gained by the time factor, which in this case is an additional 10%, and conclude that the dominant effect is the memory of the initial level.

Figure 5 compares the results of this study for 3-second eye closure period with those of the Kryszczuk study. This figure illustrates percentages of subjects who detected illuminance changes as a function of change in illuminance. In the Kryszczuk study, the initial illuminance was 475 lx and the dimming period ranged from 3.3 seconds to 120 seconds. The line shows averaged data for all his experimental conditions. Both the lines in Figure 5 show similar trends. This supports the earlier conclusion that the memorized initial illuminance is the most dominant factor. However, Figure 5 indicates that the subjects in this study were less sensitive to the illuminance changes than those in the Kryszczuk study. The difference in sensitivity between the two experiments hints that subjects might use another clue, presumably transient change in illuminance.

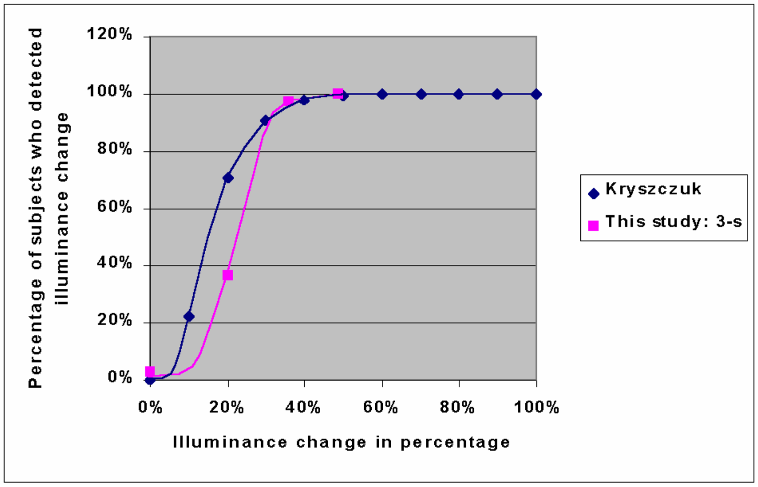


Figure 5. Percentage of subjects who detected illuminance changes vs. the degree of illuminance changes in percentage

4.3 Dimming curve study

The *dimming curve study* investigated the effects of shape, or curvature of dimming curves on detectability and acceptability of illuminance reduction. Another objective of the *dimming curve study* was to investigate the effect of task conditions on detectability and acceptability.

4.3.1. Experimental conditions

Table 4 shows the experimental conditions employed in the *dimming curve study*. The independent variables of the experiment were dimming curve function, target illuminance level, and task condition. The initial illuminance and dimming period were constant at 500 lx and 10 seconds respectively. This experiment used Equation 1 to vary the curvature of dimming curve. Constants *a* and *b* were determined according to each target illuminance. As a constant *c* that determines the curvature, 0.1, 0.2, and 0.4 were used. As the constant decreases, the function becomes more curvilinear. The constant 0.4 made the curve straighter than the constant 0.2 or 0.1. In this experiment, dimming period: *p* was constant at 10 (seconds). This is because a pilot study, done using two subjects to determine the dimming period, could not find any difference in detectable range of illuminance reduction while the dimming period ranged between 3 seconds and 120 seconds. Additionally, since a long dimming period, presumably longer than 15 seconds, for load shedding ballasts requires more sophisticated and therefore expensive control systems, the ten-second dimming period was selected as a constant experimental condition.

$$E = a \times e^{-\frac{t}{c \times p}} + b \qquad (1)$$

where E: illuminance (lx)

a, b: constants

c: a constant to change curvature

p: dimming period (second)

t: time (second)

This experiment used two task conditions: no-task and paper-task conditions. Under the no-task condition, subjects were allowed to freely gaze anywhere in the room. Under the paper task condition, subjects conducted word puzzles. Figure 6 shows a sample of the word puzzle. Four sets of word puzzles were printed in each page. Each puzzle had a 12×12 array of 12-point capital letters and a list of words. The goal of subjects was to find and mark the listed words among the 12×12 array of letters. This experiment used eleven target illuminance levels. Five of the eleven, which were higher than the initial illuminance (500 lx), were used as dummy conditions to make the probabilities of increase and decrease conditions identical.

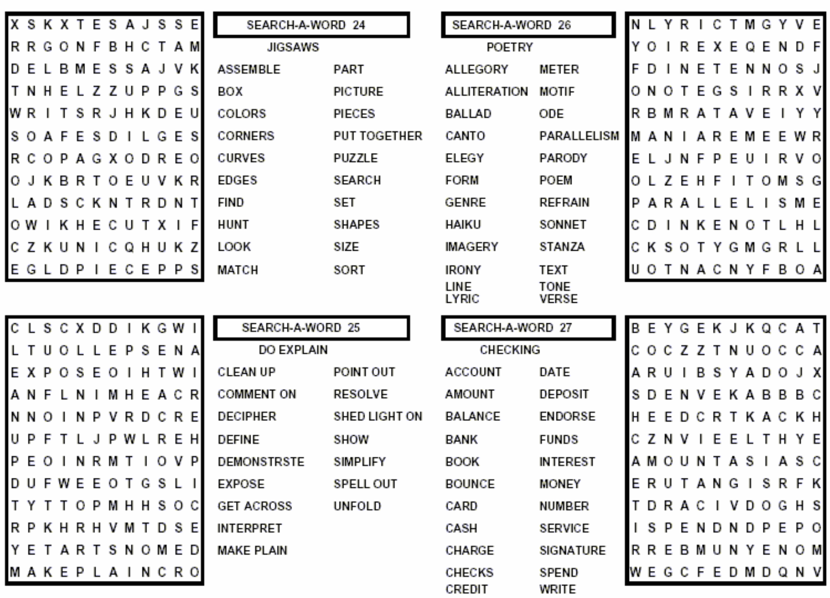


Figure 6. *Word puzzle on a page.*

The dependent variable was a subjective evaluation of whether illuminance level at a given moment was different from the initial illuminance level and whether the illuminance change was acceptable. The subjects also evaluated the acceptability using an eleven-step scale, from zero (very unacceptable) to five (neutral) and ten (very acceptable).

Table 4. *Experimental conditions*

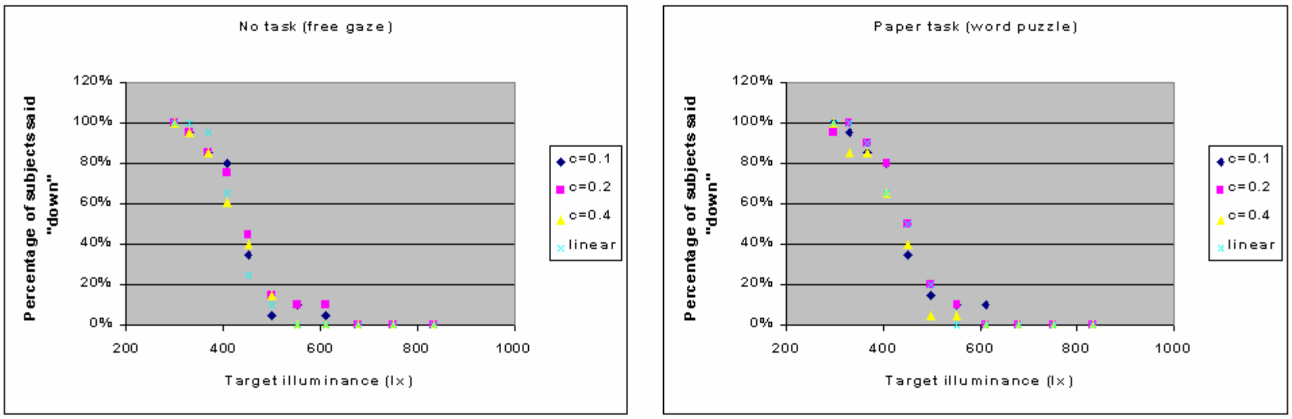
Variables	Range
Dimming curve function	Linear, 0.4, 0.2, 0.1
Target illuminance (lx)	833, 752, 679, 613, 554, 500, 451, 408, 368, 332, 300
Task condition	Paper task (word puzzle), no task (free gaze)

4.3.2. Experimental procedure

Twenty subjects, ranging from 22 to 41 in age, participated in the experiment. In the experiment, an experimenter escorted a subject to the private office and seated the subject in the chair. The subject adapted himself/herself to the brightness of the initial illuminance, 500 lx, for about five minutes. During the adaptation, the subject read and signed an informed consent form. The experimenter gave instructions about the experimental procedure to the subject. The instructions emphasized that the subject should evaluate not the final illuminance but the whole illuminance presentation in which the illuminance might or might not had changed. After the instruction, the experiment began. The experiment was divided into two sessions—paper-task and no-task sessions. The order of the sessions was counterbalanced across subjects. The subject started performing either the paper-task or no-task under the initial illuminance level of 500 lx. After 5-10 seconds the illuminance was or was not gradually dimmed according to one of the four dimming functions for ten seconds. After the ten second presentation, the experimenter asked the subject the following three questions—(1) whether the illuminance changed (“up”, “same”, or “down”), (2) whether the illuminance change (if the subject detected) was acceptable (“yes” or “no”), and (3) how acceptable was the illuminance change (if the subject detected). To respond to the third question the subject used an eleven-step scale from 0 to 10—0: “very unacceptable”, 5: “neutral”, and 10: “very acceptable”.

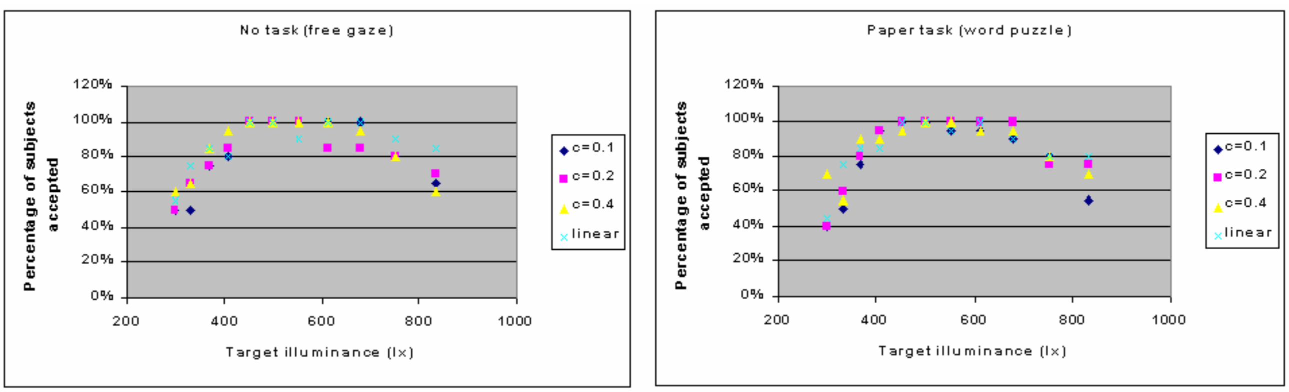
4.3.3. Experimental results

Figure 7 shows the results of the detectability of illuminance reduction. Figure 7 suggests that the dimming curvature and task conditions have little influence on the detection of illuminance reductions. Regardless of the dimming curvatures or tasks, 50 % of the subjects could detect the change in illuminance after about a 15 % reduction from the initial illuminance. Figures 8 and 9 show the results of the two acceptability evaluations—yes-or-no and rating evaluations. Figure 8 suggests that the dimming curvatures and tasks little influenced the acceptability of illuminance reductions. 50 % and 80 % of the subjects accepted illuminance reductions up to about 40% and 20% respectively. Figure 9 shows a similar trend to Figure 8.



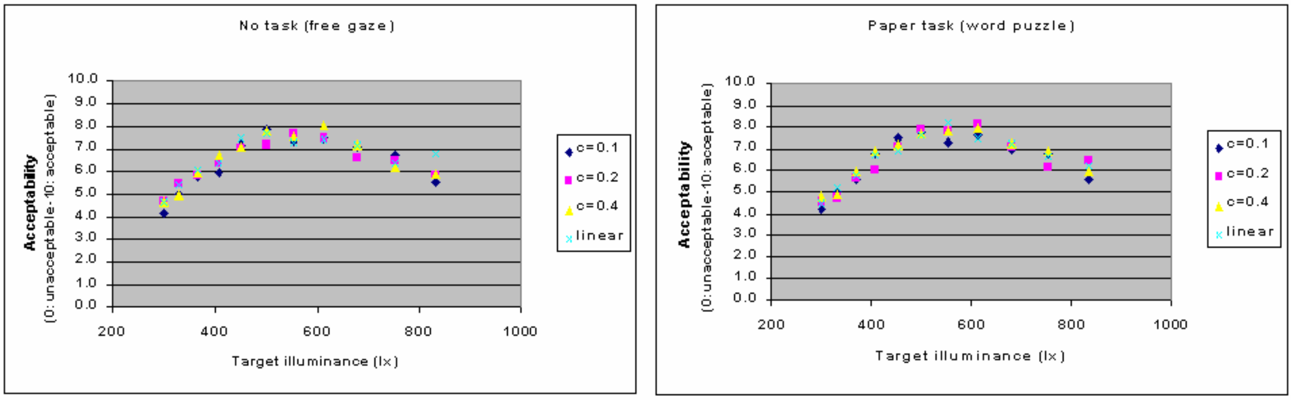
(a) No task (free gaze) (b) Paper task (word puzzle)

Figure 7. Detectability of illuminance reduction.



(a) No task (free gaze) (b) Paper task (word puzzle)

Figure 8. *Acceptability of illuminance reduction.*



(a) No task (free gaze) (b) Paper task (word puzzle)

Figure 9. Acceptability of illuminance reduction (0 to 10 scale).

4.3.4. Discussion

Figure 10 diagrams the relationship between the percentage of subjects who accepted the change in illuminance and the acceptability ratings. Figure 10 illustrates a linear relationship with high R^2 value: 0.83 between the two evaluations and therefore implies the consistency of evaluation of all the subjects.

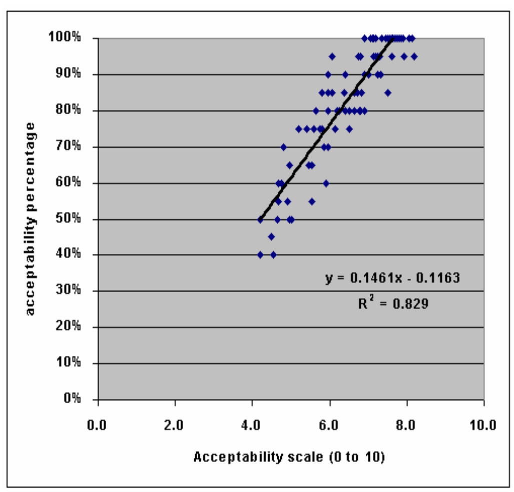


Figure 10. Relationship between acceptability rating and percentage.

4.4 Bias study

The *bias study* investigated how bias given to subjects influences the acceptability to illuminance change. Another objective of the *bias study* was to investigate how tasks performed by subjects influence the acceptability of illuminance change.

4.4.1 Experimental conditions:

Table 5 summarizes the experimental conditions. As independent variables, the target illuminance, task condition, font size, and bias condition varied. A wider range (20 lx to 1,000 lx) than the *dimming curve study* was employed because it was expected that biased subjects might accept lower target illuminance levels. For both the paper and VDT tasks, the same word puzzles as the *dimming curve study* were used. For the VDT task, a desktop personal computer (DELL, OptiPlex) with a 16” CRT screen was used. The dimming period and initial illuminance were constant at 10 seconds and 500 lx respectively. The dependent variable was subjective evaluation of whether the illuminance level at a given moment was different from the initial illuminance level and whether the illuminance change was acceptable. The subjects also evaluated the acceptability using the same eleven-step scale as the *dimming curve study*, from zero (very unacceptable) to five (neutral) and ten (very acceptable).

Table 5. Experimental conditions

Variables	Range
Target illuminance (lx)	1000, 900, 820, 740, 660, 580, 500, 420, 340, 260, 180, 100, 20
Task condition	Paper task, VDT task
Font size (point)	6, 12
Bias	No-bias, bias

4.4.2. Experimental procedure

Four subjects, ranging 25 to 28 in age, participated in the experiment. In the experiment, an experimenter escorted a subject to the private office and seated the subject in the chair. The subject adapted himself/herself to the brightness of the initial illuminance, 500 lx, for about five minutes. During the adaptation, the subject read and signed an informed consent form. The experimenter gave instructions about the experimental procedure to the subject. The experiment was divided into two sessions, one for a no-bias session and the other for a bias session. All the subjects started with the no-bias session. In each session, the subject conducted a paper task and a VDT task. Both tasks used the same word puzzles as the *dimming curve study*. Two font sizes, 6 and 12 points were used for the puzzles in both the tasks. The order of the tasks and font sizes were counterbalanced across subjects. For each of the four combinations (2 tasks $\times$ 2 font sizes), thirteen target illuminance levels were presented to the subject. In each presentation, the illuminance was gradually reduced from the initial illuminance (500 lx) to each of the thirteen target illuminance levels for ten seconds following linear dimming functions. The order of the target illuminance levels was randomized. The subject started performing either the paper task or the VDT task under the initial illuminance level, 500 lx. After the ten-second dimming presentation, the experimenter asked the subject whether the illuminance change was detectable, and if so, acceptable ("yes" or "no"). After completing the no-bias session, the experimenter gave an instruction sheet to the subject. The instructions given to subjects are listed below. All three following paragraphs were given to the subject as one general bias:

- ***Economic effect:*** *Assume you are working for a company in the capital district of NY that is on the verge of blackouts. To avoid building more power plants, we have to find a way to cut peak electricity consumption. Some feasibility studies have shown that dimming the lighting is an effective way to cut the peak load without compromising productivity. Such load shedding could reduce your company's electricity bill by about $1,500/10kW/year.*

- ***Global effect:*** *Simulations show that every new power plant will lead to an increase of* CO_2 *gas, which will cause a global warming effect. We have already seen such greenhouse effects such as an increase of the sea level, climatic change, and more frequent floods. Demand side management through load shedding ballasts can reduce the number of new power generators and therefore reduce additional contribution to the greenhouse effect.*

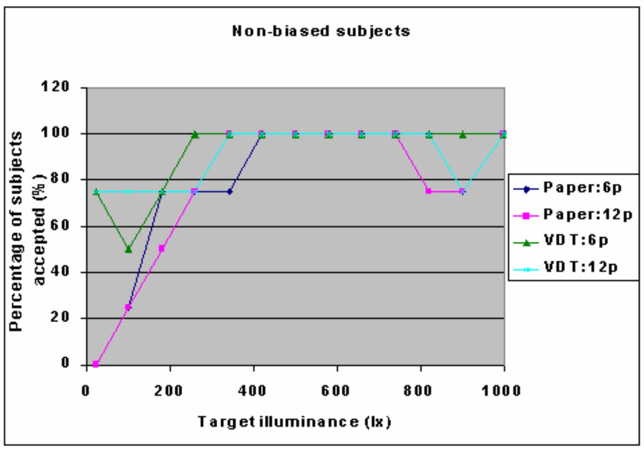
- ***Local effect:*** *New power plants and transmission lines need to go somewhere. For a variety of reasons, health, aesthetic and economic, people generally do not want such structures built near them. The reality is that people have little control over their community, and a new plant or transmission line may be built near you. Knowing that load shedding ballasts will reduce the number of new plants and transmission lines needed, how acceptable are the following dimming levels?*

After reading the instructions, the subject followed the same procedure as the no-bias session. Each session took a subject about 30 to 40 minutes. The subject conducted the two sessions on different days.

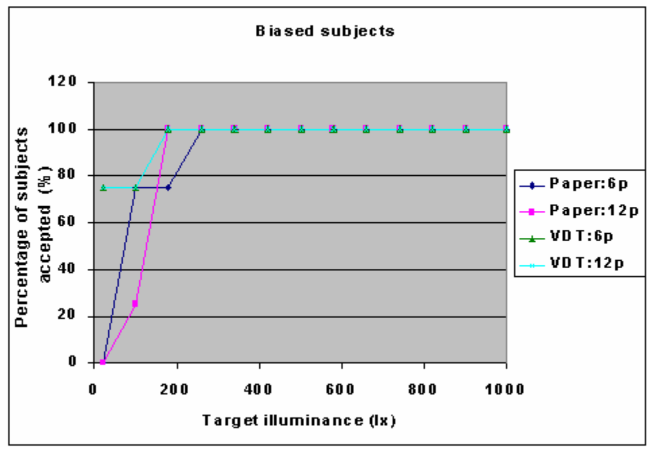
4.4.3 Experimental results

Figure 11 shows the results of the acceptability evaluations to the illuminance changes under the four task conditions—(1) paper task with 6-point font size, (2) paper task with 12-point font size, (3) VDT task with 6-point font size, and (4) VDT task with 12-point font size. Figure 11 suggests that the instruction given to the subjects between the two sessions somewhat affected the subject responses. It is apparent that the acceptable dimming range by biased subjects is wider than that by non-biased subjects, although the probability curves are not smooth because of the small sample size. Figure 12 compares acceptable dimming ranges between biased subjects and non-biased subjects. Each of the two lines shows the average of the percentages for all four task conditions. The comparison of illuminance reductions, which all four subjects accepted, between the non-biased subjects and the biased subjects shows that the acceptable target illuminance of the biased subjects was lower by one to two steps, 80 lx to 160 lx respectively, than that of the non-biased subjects. The comparison of the acceptable target illuminance levels between the four task conditions in each of the graphs (a) and (b) in Figure 11 suggests that the acceptable target illuminance for the VDT task tends to be lower than that for the paper task. It also suggests that the lager font size might lower the acceptable target illuminance.

The results of this study imply that if the motivation of occupants towards energy savings is raised, occupants may accept larger reductions in illuminance. However, further studies need to be done with more subjects to obtain more reliable data.



(a) Non-biased subjects



(b) Biased subjects

Figure 11. *Acceptability of illuminance reduction in the bias study*

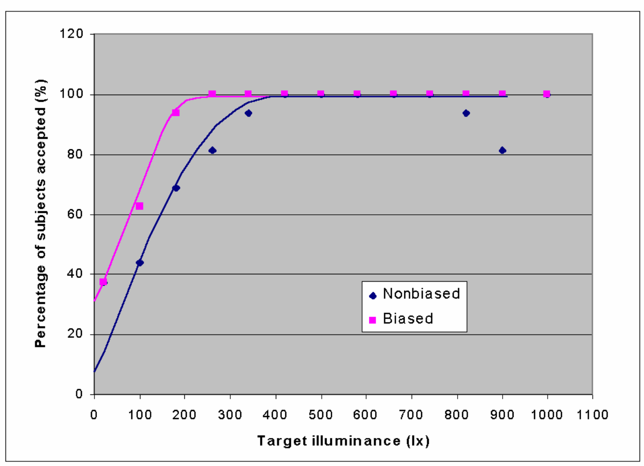


Figure 12. Acceptability of illuminance reduction for biased subjects and non-biased subjects

5. Conclusions

The *memory study* indicates that occupants are able to memorize the initial brightness of their surroundings and respond to illuminance changes based on this memory. Lengthening the time in the dark from exposure to the initial lighting conditions appears to decrease sensitivity to illuminance reduction, but this result is potentially confounded with light adaptation, thereby possibly diminishing the magnitude of this effect. The *dimming curve study* suggests that the dimming curvature and task conditions have little influence on the detection of illuminance reductions. It was also found that regardless of the dimming curvatures or tasks, 50 % of the subjects could detect a reduction of initial illuminance of about a 15 % or greater. With regard to acceptability, the experimental results suggest that the dimming curvatures and tasks had little influence on the acceptability of illuminance reductions. The *bias study* suggested that the acceptable dimming range of biased subjects is wider than that of non-biased subjects, offering an additional 20 to 30% acceptable illuminance reduction. More precise results with smoother probability curves, especially for the specific task analyses require a larger number of subjects. That data is now being collected as this work continues.

6. Implications for load shedding

If the amount of power reduction for effective load management requires dimming by more than 15% then there is a high probability that people will notice the change in illuminance, no matter how that change is accomplished. Fortunately, changes of this magnitude and up to about 25% are acceptable to most people. Furthermore, by educating people on the reasons for and benefits of load shedding, which is called biasing when under experimental conditions, the acceptable dimming range can be extended to 50% or more. This provides great insight into how to manage a successful load-shed program. To maximize demand savings, education of the public, or affected persons, should be a high priority.

7. Further study

It is important to add more subjects to the *bias study* to specify acceptable dimming ranges for biased and non-biased occupants. It is also useful to investigate how dimming periods longer than two minutes affect the acceptability of illuminance reduction. Eventually, based on our findings, we will have to conduct field studies in real commercial offices to verify whether occupants are comfortable with the specified requirements of the dimming range, curve, and speed and evaluate how much electric energy can be saved through the load shedding system.

Acknowledgements

The authors would acknowledge Connecticut Light and Power for funding this research.

The authors would like to acknowledge Peter Boyce and Mark Rea for their comments on the experiments. The authors would like to thank Lei Deng, Jean Paul Freyssinier, Chao Ling, and Francisco Garza for their technical support.

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