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END USERS' KNOWLEDGE, BELIEFS, AND PREFERENCES FOR LIGHTING

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OBJECTIVE

An understanding of end users is necessary if one is to design to meet human needs. This study measured four broad concepts related to lighting to contribute to our understanding of end users in this domain: knowledge about technical aspects of lighting; beliefs about the effects of lighting on people; preferences regarding lighting; and importance of lighting.

RESEARCH DESIGN

The study was a survey of a large group of university undergraduates. Sets of questions relating to each of the four concepts were created from the literature on lighting and interviews with other subjects. The lighting types and settings deliberately referred to circumstances familiar to these subjects. The questionnaire was completed during university classes.

ANALYSIS

Descriptive statistics and inferential analyses of specific hypotheses were used to assess the state of these end users' knowledge, beliefs, preferences, and ratings of the importance of lighting and the interrelations between these variables.

KEY FINDINGS

The results show that lighting is important to laypeople and reveal that people to whom it is important desire more control over lighting. These subjects perceived that they had little control over lighting but desired much more. A large percentage of respondents believed that fluorescent lighting can be detrimental to one's health, and those who endorse these views about health effects also believe that natural daylight is superior to electric light.

CONCLUSION

Design to meet human needs will improve if better understanding is gained of the beliefs, preferences, and knowledge of the client. This report includes specific suggestions for applications and provides pointers for both designers and researchers.

The awakening environmental consciousness that receives so much media attention these days includes careful attention to the potential energy savings from innovative lighting designs (e.g., Goldstick, 1990). Designers seek new ways to put light only where it is needed and to achieve energy savings through the appropriate use of daylight. New technologies such as compact fluorescent lamps allow illuminance levels to be maintained while saving electricity, and their use has been encouraged by utility companies through rebate programs. The lighting industry has undergone revolutionary changes.

Human needs ought not to be forgotten in the rush to conserve energy and to use light in innovative ways. Ryan (1991) suggested that the coming years will bring intense debate between advocates of technological and human-needs approaches to lighting design. "People are not machines," wrote

Julian (1987, p. 157), who described the state of post-occupancy evaluation of energy-efficient projects as a "deafening silence."

Research Design and Hypotheses

This paper reports the initial development of a survey tool to assess end users' knowledge about common types of lighting, beliefs about the effects of light on people, preferences regarding interior lighting, and the importance people attach to lighting. The results will be of interest to designers and to facilities managers who wish to tailor lighting design to individual needs and tastes.

Survey data establish a baseline; according to Kerlinger (1986), surveys "attempt to determine the incidence, distribu-

*There is little systematic information available about end users' opinions
of the lighting they encounter.*

tion, and interrelations among sociological and psychological variables and, in so doing, usually focus on people . . . and their beliefs, opinions, attitudes, motivations, and behavior" (p. 378). The aim of the present study was to describe the preferences and beliefs about lighting that exist in the population.

Further analyses tested six hypotheses, developed from suggestions in the literature on lighting and from the research team's prior experience in lighting research, about interrelationships between the variables. The relevant research is reviewed below. The hypotheses are as follows:

1. People to whom lighting is important are more knowledgeable about lighting.
2. People who are more knowledgeable about lighting desire more control over lighting.
3. People to whom lighting is important desire more control over lighting.
4. People who believe that bright light increases productivity will prefer bright light.
5. People who endorse beliefs about negative effects of fluorescent light or favorable effects of certain types of light will prefer natural light to other types.
6. People who endorse beliefs about the effects of lighting on health will also endorse beliefs about the superiority of natural light over other types.

The hypotheses were generated following a reading of the lighting research and design literatures, concentrating on behavioral research into the effects of lighting on people. A brief review of the relevant work is provided here.

Lighting researchers have identified certain consistencies in users' preferences. Many people express a strong preference for natural daylight rather than electric light (Heerwagen & Heerwagen, 1986), although this may also reflect a preference for a view of the outdoors. This opinion is shared by Stone (1992), who, in reviewing the literature on fluorescent lighting and health, concluded that the lack of visual variety and absence of windows are more powerful influences on people than is radiation from fluorescent lamps. Awareness of the literature on preferences for daylight, fluorescent lighting, and health led to the predictions in Hypotheses 5 and 6.

Individuals differ in their lighting preferences. For example, in a study published after these data were collected, people diagnosed as having Seasonal Affective Disorder preferred brighter rooms in all seasons than people who did not suffer from this disorder (Heerwagen, 1990). Also, older workers tend to select higher desk illuminances than younger workers, although individuals differ widely and unpredictably in the

pattern of room luminances they choose when given freedom to do so (Tregenza, Romaya, Dawe, Heap, & Tuck, 1974).

Up-to-date information about innovative office lighting emerged from two experiments conducted by Pacific Power at around the same time as these data were collected. Both in short-term and longer-duration exposures (Moss/Noedel Research, 1990; Katzev, 1992), office workers preferred an office lit with direct/indirect luminaires over three other offices lit with varying types of direct fluorescent light. The subjects believed that this office was too dim, however, and that supplementary task lighting would be needed for extended work there. Data on the subjects' beliefs about lighting were not collected, but it is probable that people who wanted brighter light in that office for sustained work would also believe that bright light improves productivity. This relationship is tested in Hypothesis 4.

People associate activities and illuminance levels in predictable ways (Butler & Biner, 1987). For instance, intimate conversations would be expected to take place in settings with relatively low illuminance. Furthermore, the importance of lighting in a given setting was strongly related to the desire to control the lighting in that setting (Hypothesis 3 in the present study). Biner, Butler, Fischer, and Westergren (1989) have expanded this work to include social situations and task demands and have found that for nonvisual tasks, social situation is an important determinant of light level preference. For visual tasks, the effect of social situation is weaker.

There is little systematic information available about end users' opinions of the lighting they encounter. A literature search revealed only one such survey, the 1979 Louis Harris survey ("Office Lighting," 1980). The survey results showed that 92% of respondents worked in offices lit with fluorescent lights; 70% preferred overhead lights, and 32% felt that task lighting would be preferable to overhead in encouraging productivity (the survey did not give separate options for task lighting alone versus task combined with ambient lighting). Fifty-four percent felt that it is very important to have a say in the type of lighting where they work, but 57% believed that better lighting would not improve their productivity. Hypotheses 1 and 2 emerged from speculation about possible explanations for these survey results.

Lighting Beliefs and Design

Lighting designers apparently believe that lighting has certain behavioral or mood-altering effects on people. Examples of such statements are common in the popular literature. For example: "The mood of the space—the excitement or peace it communicates to its users, and its attraction for certain personalities—is influenced by lighting" (Smith & Bertolone, 1986, p. 12). "If you . . . prefer an active mood in the space, choose

The responses to three questions show that a large percentage of the subjects believed that natural light is superior to other types.

They also were asked their preferences for quantity of light and whether they desired to control their lighting. The quantity of light and control items were scaled on Likert-type 5-point scales coded 0 to 4. The brightness questions referred specifically to studying and classroom situations so that they would be meaningful to the students.

Importance questions. The ratings of lighting importance were made in the form of agreement or disagreement with general statements, also using Likert scoring scaled 0 to 4. Examples of the statements include "Lighting is important to my sense of well-being."

Results

This survey was designed along the lines of an opinion poll. Descriptive statistics for each aspect of the survey provide an overview of these end users' knowledge, beliefs, and preferences for lighting. In addition, certain specific hypotheses were tested based on prior research and experience. These results must be treated with caution as exploratory only. The frequency distributions of most of the variables were strongly skewed, and some were dichotomous (possible values were 0 and 1).

Knowledge

The knowledge questions were scored 1 if correct and 0 if incorrect, and each subject's total score was the sum of the item scores. The average score was 6.3 out of 10 (the standard deviation was 2.13), and the range was from 0 to 10. The questions and the percentage correct for each are displayed in Table 1.

Only 38.6% understood that fluorescent lamps do not produce light from the glowing of a filament; however, 69.1% correctly answered that fluorescent lamps produce less heat than incandescent lamps.

One item asked whether incandescent lamps produce light that is more similar to sunlight than fluorescent lamps (no specific type was named, but cool white and warm white lamps were probably most familiar to these subjects). Only 18% correctly responded that they do not.

Beliefs

The ten items and the agreement with each are shown in Table 2. The responses to three questions show that a large percentage of the subjects believed that natural light is superior to other types: "Natural daylight is better for working under than artificial light" received 68.8% acceptance; "Lighting that simulates daylight is a better source than other kinds of light, and people do better work under such lighting," 65.5% acceptance; "People feel happier when working under light that is similar to natural daylight," 77.3% acceptance.

Table 1

Lighting Knowledge Quiz

Question	% correct
K1. Most classrooms use incandescent lighting. (False)	65.7
K2. Incandescent lights use long tubes. (False)	74.0
K3. Fluorescent lights produce less heat than incandescent lights. (True)	69.1
K4. The filament in a fluorescent light glows when an electric current is passed through it; this is where the light comes from. (False)	38.6
K5. Fluorescent lamps come in one color. (False)	69.0
K6. The reason why so many classrooms are lit the way they are is to give efficient light at low cost. (True)	80.2
K7. Fluorescent lights sometimes flicker noticeably. (True)	90.7
K8. Incandescent lights produce a warmer, more flattering color to people's appearances. (True)	64.7
K9. Incandescent light is more similar to sunlight than fluorescent light. (False)	18.0
K10. Thomas Edison invented the incandescent light bulb. (True)	61.9

Regarding the questions about health effects, the degree of agreement varied. Three-quarters of the respondents reported agreement with the statement "Reading under dim light causes eye damage." The largest group (41.8%) believed that fluorescent lights are detrimental to health (31.8% disagreed with this statement, and 26.4% did not know). Only 25.1% agreed that flickering fluorescent lights can trigger epileptic seizures in some susceptible people.

Preferences

The questions and the frequency distributions for the questions about brightness preferences are presented in Table 3. For studying or reading, the students reported an average illuminance preference that was quite bright, in that 66.4% preferred light levels in the two brightest categories (3 or 4, where 0 = dim and 4 = bright). Classrooms on campus were generally rated as appropriately bright: 61.8% rated them as neutral (= 2, where 0 = too dim and 4 = too bright), 15.6% responded 0 or 1, and 22.5% responded 3 or 4. Although we do not have data on the actual illuminances achieved in various campus buildings, the design criterion at this university is 800 lux.

A slightly different pattern of preferences was reported for library study areas, which were rated as neither too bright nor

There is evidence. . . that the beliefs people hold about lighting can influence their performance and their mood.

a pendant that allows the light to go up as well as down" (Grosslight, 1984, p. 28).

These beliefs have no empirical support in the scientific literature, although they may accurately reflect experience. It is not known whether people who are not lighting specialists would agree with such statements. There is evidence, however, that the beliefs people hold about lighting can influence their performance and their mood (Veitch, Gifford, & Hine, 1991). People who received information about the expected effects of the lighting under which they worked performed better on a reading comprehension test and reported greater arousal than did people who had not received such information.

These results reveal that it is important for decision makers to understand what beliefs and knowledge users hold about lighting and to use this information in making their lighting choices so as to predict how the users will respond. This study is one contribution toward that effort.

Method

Subjects

The participants were 1,057 undergraduate students in social science courses at the University of Victoria, a medium-sized university in British Columbia, Canada. Personal data were not collected, but the group from which these subjects were drawn consisted of 60 percent women and 40 percent men, ranging in age from 18 to 35. They completed the survey voluntarily during laboratory periods in lecture theaters at the university.

Survey

General description. The questionnaire assessed four dimensions: knowledge about lighting, beliefs about the effects of lighting, preferences for lighting, and ratings of the importance of lighting to the individual. There were 35 items in all.

The items refer generically to incandescent and fluorescent lighting because informal interviewing with potential subjects indicated that these types were the most familiar to them. Although many other lighting technologies are available (e.g., metal halide and other HID lamps, compact fluorescents, and tungsten-halogen lamps), the subjects did not recognize them by name.

The questionnaire was printed in ten-point high-contrast black type on white paper. Respondents used computer-readable answer sheets to record their responses in pencil. The illumination in the lecture theaters at the time of the survey was direct fluorescent and indirect incandescent lighting providing approximately 800 lux on the writing surfaces.

Knowledge questions. The questions about lighting knowledge were in the form of statements that the respondent rated as

being true, false, or "don't know." The items were created from statements encountered in the lighting design literature and in the *Handbook of the Illuminating Engineering Society* (Illuminating Engineering Society of North America [IESNA], 1987) and from comments made by participants in previous lighting research projects at the university. The knowledge questions dealt with objective facts about technical aspects of fluorescent and incandescent lighting.

Belief questions. The questions about lighting beliefs were similar to those about knowledge except that they referred to effects lighting might have on people. They were scored in the same manner as the knowledge questions and originated in the same sources.

The evidence generally does not show that people experience any of the effects from lighting referred to in these questions, with the exception of question 3, "Bad lighting leads to eye-strain and headache." For example, if there is a veiling reflection of a light source in a VDT screen, the lighting design might be described as bad, and the viewer might adopt an odd posture to minimize the effects of glare. This could result in headache.

The statement "Brighter light leads to greater productivity" is arguable. Gifford, Hine, and Veitch (in press) conducted a meta-analysis of the literature on illuminance effects on intellectual task performance and found a small effect in which improvements in performance followed increasing illuminance. Many investigations were ineligible for the meta-analysis because their statistics were inadequately reported. Furthermore, it appeared that when the effect of differences in the adaptation time allowed in each experiment was removed, illuminance had no effect on performance.

The weight of research evidence does not support the remaining belief statements. Experimental evidence has consistently failed to find any effect of light source on performance or mood (e.g., Boray, Gifford, & Rosenblood, 1988; Veitch, Gifford, & Hine, 1991). Stone (1992) reviewed the literature on fluorescent lighting and health and concluded that "interior electric lighting does not pose an irrevocable health hazard" (p. 60); he summarized the specific issues covered by the items in this questionnaire.

Preference questions. The preference questions related to preferences for lamp types in study areas at home, in library study areas, and in a hypothetical office ("If I worked in an office, I would prefer . . ."). The questions consisted of checklists in which subjects indicated whether they preferred natural daylight, fluorescent overhead lighting, fluorescent task lighting, incandescent overhead lighting, or incandescent task lighting in each setting. They were permitted to mark as many types as they wished.

had no control over the lighting where they study, and 41.5% wanted complete control over this lighting.

Three items concerned preferences for particular types of lighting in particular settings. The preferences were markedly different for home study areas in comparison to library study areas and a hypothetical office setting. The frequencies are shown in Table 4.

Natural daylight was preferred in settings where people might expect to work during daylight hours. At home, these students preferred incandescent task lighting over any other. These results are consistent with the responses to other parts of the survey.

Importance

When asked how frequently they notice, upon entering, the

way a room is lit, 87.4% gave scores on the high end of the scale (scores of 3 or 4). The importance of the total effect of the lighting in a room was rated highly by 63.1% of the students (scores of 3 or 4, where 0 = not at all important and 4 = very important). The questions and the frequency distribution of responses are shown in Table 5.

Other questions asked about the importance of lighting for students' studying effectiveness, sense of well-being, and mood. As Table 5 shows, over three-quarters (78.6%) agreed that lighting is important for studying. The students also felt that lighting is important to their well-being (60% agreed) and mood (63.9% agreed). When asked whether they agreed or disagreed with the statement "As long as I can see to read, I don't care about the lighting in a room," 75.1% indicated that they do care about the lighting in a room.

Inferential Analyses

The data set was used to test specific hypotheses about the relationships between various questions in the survey. The hypotheses and their outcomes are summarized in Table 6. A variety of statistical tools were employed to test these hypotheses. Full explanations of each procedure are beyond the scope of this paper, but excellent introductions are presented in Kerlinger (1986) and Tabachnick and Fidell (1983).

Scale scores. Attempts were made to increase the power of these comparisons by creating scales out of the items in each group. The analyses began with principal components analysis (a type of factor analysis), followed by varimax rotation of the factors, separately for each group of items: Knowledge, Beliefs, Preferences, and Importance. The goal of this analysis was to produce composite scores that summarize the questions in the conceptual group. For a composite score to be meaningful, the average of all possible intercorrelations be-

Table 4

Preferred Lighting Types for Different Settings (in percent)

	<i>Home</i>	<i>Library</i>	<i>Hypothetical office</i>
Incandescent			
Task light	58.9	26.8	16.9
Ceiling	22.7	10.7	20.0
Fluorescent			
Task light	7.7	7.0	3.8
Ceiling	2.2	12.3	13.9
Natural daylight	8.3	42.8	45.2

Note: Combinations of lighting types within settings were treated as missing data. For Home, N = 866. For Library, N = 933. For Hypothetical office, N = 921. Columns may not sum to 100% because of rounding error.

Table 5

Frequency Distributions of Responses to Questions about Importance of Lighting

	<i>Frequency of Responses (%)</i>				
	<i>0</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>
11. When I enter a room, I notice the way it is lit.	2.9	9.6	38.2	30.1	19.1
12. The total effect of the lighting in a room is important to me.	2.9	7.8	26.1	38.2	24.9
13. Lighting is important to my studying effectiveness.	2.1	4.8	14.5	32.9	45.7
14. Lighting is important to my sense of well-being.	5.9	9.1	25.1	26.0	34.0
15. Lighting is important to my mood.	8.4	8.9	18.8	25.8	38.1
16. As long as I can see to work, I don't care about the lighting in a room. (reverse-coded)	4.5	7.3	13.1	26.4	48.7

Note: For all items, higher scores reflect greater importance given to lighting. The anchor descriptors for each question were 0 = disagree and 4 = agree. Item 16 was reverse-scored to maintain this meaning.

Although most students perceived that they lacked control over the lighting in their campus study spot, most wished that they had such control.

Table 2

Acceptance of Common Beliefs about Lighting (in percent)

<i>Belief</i>	<i>Accept</i>	<i>Don't accept</i>	<i>Don't know</i>
B1. Brighter light leads to greater productivity.	25.0	55.3	19.7
B2. Fluorescent lights are bad for your health.	41.8	31.8	26.4
B3. Bad lighting leads to eyestrain and backache.	88.1	8.2	3.8
B4. Natural daylight is better for working under than artificial light.	68.8	18.8	12.4
B5. Lighting that simulates daylight is a better source than other kinds of light, and people do better work under such lighting.	65.5	22.6	11.0
B6. People feel happier when working under light that is similar to natural daylight.	77.3	7.3	15.4
B7. Flickering fluorescent lights can trigger epileptic seizures in some susceptible people.	25.1	46.7	28.2
B8. Reading under dim light causes eye damage.	74.7	16.7	8.6
B9. Exposure to bright lights during the winter can prevent depression or the "winter blues."	48.0	28.3	23.7
B10. Given that human beings have evolved to live under the sun, we should use artificial sources of light as little as possible.	35.3	36.5	28.2

Table 3

Brightness Preference Questions and Frequencies of Responses

	<i>Frequency of Responses (%)</i>				
	<i>0</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>
P1. For studying or reading, in general I prefer to have:	1.0	3.9	28.3	50.4	16.4
P2. Classrooms here, in general, are:	2.9	12.7	61.8	16.9	5.6
P3. The library study areas, in general, are:	4.8	21.3	55.3	15.0	3.4

Note: The scale anchors were 0 = dim (P1) or too dim (P2, P3); 4 = bright (P1) or too bright (P2).

too dim (= 2) by 55.3%, whereas 26.1% responded 0 or 1 and 18.6% responded 3 or 4. That is, more students rated library study areas as too dim than rated classrooms as too dim.

Two survey questions dealt with control over lighting in study areas on campus. The first asked about the degree to which the students felt they could control the lighting in the place where they study; the second asked how much control they wished they could have. The results appear in Figure 1.

The pattern is clear: Although most students perceived that they lacked control over the lighting in their campus study spot, most wished that they had such control. The largest group responded in the extreme on each item; 56.4% felt they

Figure 1

Perceived and desired control over lighting in on-campus study areas.

The underlying message in these results is that people believe that lighting is important to the achievement of a healthy and productive life, and in general they prefer the type of lighting that they believe will help them reach that end.

Table 7**Summary of Canonical Correlation Analysis of Beliefs about Lighting and Preferences for Natural Light**

	First canonical variate Variate loading
Belief (X) Set	
B2	.29
B4	.86
B5	.47
B6	.48
B7	-.21
B10	.60
X Variance Explained	.28
Redundancy	.04
Preference (Y) Set	
Home	.31
Library	.81
Office	.90
Y Variance Explained	.52
Redundancy	.07
Canonical Correlation	.36

required the deletion of 234 cases so this analysis is based on data from 834 respondents.

Table 7 shows the results of this analysis. There was one statistically significant canonical correlation, which was .36. The variate loadings in the table are the correlations of scores on the individual questions with the scale score for their respective sets. The patterns show that the acceptance of beliefs in the X set relate to scores on the preference items in the Y set. This supports the hypothesis.³

Hypothesis 6 stated that individuals who endorse beliefs about the effects of lighting on health will also endorse beliefs about the superiority of natural light over other types. The theoretical basis for this hypothesis was the assumption that a general distrust of modern technology underlies both sets of beliefs.

The X variables were B2, B3, B7, B8, and B9, all relating to beliefs that improper lighting can be harmful to human health (Health set). The Y set of variables was made up of B4, B5, B6, and B10 (Natural light set); as shown in Table 2, these variables relate to beliefs that natural daylight or light that simulates daylight improves mood and work performance and is preferable to other types. Missing data required the deletion of 16 cases; the results are based on data from 1,041 individuals.

The summary of this analysis appears in Table 8. There were two significant canonical correlations. For the first, less belief in general health effects of lighting (B2, B3, B9) and more belief in fluorescent lighting as a trigger for epilepsy (B7) relates to less belief in the beneficial effects of natural light or light similar to daylight (B4, B5, B6, B10). This is consistent with the hypothesis, although the reversal for item B7 is a puzzle. People who believe that lighting can affect health also believe that natural light is superior to other types of light.⁴

The second canonical correlation is very weak but seems to describe a pattern of beliefs relating to the acceptance of electric light sources for workplace lighting. For the Health (X) set, the second composite score (canonical variate) is associated with less suspicion of fluorescent lighting (less belief in fluorescent light as a cause of ill health and as a trigger of epileptic seizures and more belief in bright light as a cure for winter blues). For the Natural light (Y) set, the second canonical variate is difficult to define because of the opposite directions of the two factor loadings. It is defined by less belief that natural light is better for working than electric light but more belief that people are happier working under light that is similar to natural daylight.

Table 8**Summary of Canonical Correlation Analysis of Beliefs about Health Effects of Lighting and Natural Lighting**

	First canonical variate Variate loading	Second canonical variate Variate loading	
Health (X) Set			
B2	-.71	-.59	
B3	-.39	-.18	
B7	.32	-.35	
B8	-.09	.06	
B9	-.56	.73	
X Variance	.22	.21	Total: .43
Redundancy	.012	.004	.016
Natural light (Y) Set			
B4	-.39	-.75	
B5	-.70	.01	
B6	-.57	.46	
B10	-.79	-.20	
Y Variance	.40	.20	Total: .60
Redundancy	.021	.004	.025
Canonical correlation	.23	.13	

Table 6

Summary of Hypotheses and Significance Test Conclusions

Hypothesis	Support
1. People to whom lighting is important are more knowledgeable about lighting.	Y
2. People who are more knowledgeable about lighting desire more control over lighting.	N
3. People to whom lighting is important desire more control over lighting.	Y
4. People who believe that bright light increases productivity will prefer bright light.	Y
5. People who endorse beliefs about negative effects of fluorescent light or favorable effects of certain types of light will prefer natural light to other types.	Y
6. People who endorse beliefs about lighting effects on health will also endorse beliefs about the superiority of natural light over other types.	Y

tween the questions should be high (values above .60 are acceptable). This statistic is called Cronbach's alpha, and it is a measure of internal consistency reliability.

This strategy produced two scales with acceptable internal consistency reliability, one for General Knowledge and one for Importance. They are described below.

In the principal components analysis of the Knowledge items, it appeared that three items were inconsistently related to the others. These were dropped to form a more reliable scale, scores on which are the average of scores on items K1 to K4, K7, K8, and K10 (i.e., excluding K5, K6, and K9; see Table 1). Internal consistency reliability of this General Knowledge scale was acceptable (Cronbach's alpha = .70; $M = 0.66$; $SD = 0.27$; range 0–1).

Also following the principal components analysis, an Importance scale was constructed by averaging scores on the six Importance items (I6 was reverse-coded for consistency of interpretation). The internal consistency reliability of this scale was good (Cronbach's alpha = .78; $M = 2.82$; $SD = 0.75$; range 0–4).

The principal components analyses did not produce any other scales with acceptable internal consistency reliability (Cronbach's alpha < .50). Further analyses proceeded using the scale scores for General Knowledge and Importance and specific items as appropriate.

Bivariate correlational tests. Hypothesis 1 stated that people to whom lighting is important are more knowledgeable about

lighting. This hypothesis was supported by the statistically significant correlation between General Knowledge and Importance ($r = .12$, $p < .01$, two-tailed).

Hypothesis 2 stated that people who are more knowledgeable about lighting desire more control over lighting. This hypothesis was not supported: There was no correlation between General Knowledge and Desired Control ($r = .00$, n.s.).

Hypothesis 3 stated that people to whom lighting is important will desire more control over lighting. The correlation between Importance scores and Desired Control, $r = .28$, was statistically significant ($p < .01$, two-tailed).¹

Hypothesis 4 stated that people who believe that bright light increases productivity will prefer bright light. Scores on questions B1 and P1 were used to test this hypothesis. This relationship was supported: $r = .15$, $p < .01$.

Canonical correlation analyses. Canonical correlation analysis is used to test hypotheses about relations between groups of variables. Tabachnick and Fidell (1983) have written a concise description of the mathematics behind this complex statistical tool. For the present purpose, consider the analysis as a two-step process that determines the degree of association between two sets of variables. (This is a simplification. In fact, the two steps are simultaneous calculations. Throughout this section, the more technical details are presented in footnotes.) In step one, each group of variables is reduced into composite scores in a similar fashion to the principal components analysis used earlier. As with any multivariate technique, there are as many possible solutions as there are variables in the set. Some of these composites characterize their set better than others (that is, they explain more of the variability).

In step two, the composite scores from the two sets are paired in order of the proportion of variability they explain, and these pairs of scores are then correlated. This is the *canonical correlation*.²

Hypothesis 5 was: People who endorse beliefs about negative effects of fluorescent light or favorable effects of certain types of light (Belief (X) variables) will prefer natural light to other types (Preference (Y) variables). Suspicion about fluorescent technology, it was theorized, would lead to the rejection of electric light sources in general (see Stone, 1992).

To test this hypothesis, scores on items B2, B4, B5, B6, B7, and B10 made up the Belief (X) set. They were coded -1 = do not accept, 0 = don't know, and 1 = accept, with positive numbers reflecting beliefs that lighting affects behavior, mood, or health. The preferences for particular types of light at home, library, and hypothetical offices were recoded so that natural light was scored 1 and other types 0. These three scores for each individual made up the Preference (Y) set. Missing data

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on what information he or she can recall, which may be no more substantial than the latest complaints from another tenant or the latest and loudest claims from a manufacturer.

A wrong choice will result in more time and money being spent addressing ill-founded complaints from occupants and may include lost productivity and increased absenteeism. If the decision involves energy-efficient lighting, and if the new system is perceived as risky because occupants will not accept it, there will be direct costs of energy savings not realized. The best lighting decisions will take account of the best available knowledge about both the technology and the people who will use the lighting system, thereby avoiding these undesirable outcomes.

Beckstead and Boyce (1992) provided evidence that beliefs about lighting do influence decisions. They reported the results of an investigation into beliefs and attitudes toward lighting and residential lighting choices. Participants in their study who reported believing that fluorescent light can have adverse effects on people were less likely to use compact fluorescent lamps in their homes.

Conclusions

The information obtained in this survey contains pointers for both designers and researchers. This is the first survey to demonstrate that a significant proportion of the population believes that fluorescent lighting causes ill health, although empirical research has not demonstrated such an effect (Stone, 1992). The misconceptions shown here about technical aspects of lighting have also not been documented previously. We know now that people lack correct knowledge about how the more complex lighting technology (e.g., fluorescent lamps) works, but what knowledge about lighting they have will affect their behavior (Veitch, Gifford, & Hine, 1991).

The better the designer understands the unspoken beliefs, preferences, and understanding that the client brings to each discussion, the more successfully the designer will be able to communicate with the client. This is particularly true regarding a feature such as lighting, which is amenable to fine-tuning by the client (or other end users such as the occupants of individual offices) after the job is officially finished. The designer who can anticipate how the client might be tempted to alter the design will be more successful in meeting the client's needs and desires.

Some specific applications can be suggested based on these results. These results show that students prefer to have control over the lighting where they study. Moreover, the desire to have control over lighting is greater for people to whom lighting is important. Designers might attempt to use this knowledge to tailor the degree of individual control to their knowl-

edge of the client's belief about the importance of lighting. Further research will be needed to identify the most important features people would like to control: illuminance, veiling reflections, direction, luminance distribution, or spectral qualities might all be targets for user control.

Illuminating Engineering Society tables recommend ranges of illuminance for tasks, difficulty levels, and users' ages (IESNA, 1987). This survey demonstrated that individuals who believe that bright light is important for productivity will prefer brighter light. One might factor in this information, together with knowledge of the age of the user, the task involved, and its difficulty, to select an illuminance target for a design suited to the individual. This is an example of how beliefs can influence preferences; other relationships between beliefs and preferences await further research.

Knowledge of lighting beliefs and preferences may result in difficult choices for designers. People want lighting that simulates daylight, but they distrust fluorescent light; yet fluorescent sources are the predominant choice for daylight-simulating lighting. The canonical correlation analyses confirmed the speculation that people who endorse beliefs about health effects of lighting also endorse beliefs about the superiority of natural light and lighting that simulates daylight over other types. Furthermore, people who endorse beliefs that imply a suspicion of fluorescent light prefer natural daylight. Nonetheless, electric lighting is a necessity at northern latitudes; daylight alone is not a practical lighting solution.

Future Research

Further work continues to refine the survey reported here. The relationships between lighting beliefs and beliefs about other effects of the physical environment on people are one target for the ongoing investigations. Other research directions include the elaboration of the effects of such beliefs on office task performance and mood and a more detailed study of preferences for different office lighting options. These projects and others in this field will complement the technical progress in the lighting industry and the creative efforts of designers to produce innovative lighting that responds to human needs.

References

- Beckstead, J. W., & Boyce, P. R. (1992). Structural equation modelling in lighting research: An application to residential acceptance of new fluorescent lighting. *Lighting Research and Technology*, 24, 198-201.
- Biner, P. M., Butler, D. L., Fischer, A. R., & Westergren, A. J. (1989). An arousal optimization model of lighting level preferences: An interaction of social situation and task demands. *Environment and Behavior*, 21, 3-16.
- Boray, P., Gifford, R., & Rosenblood, L. (1989). Effects of warm white, cool white, and full-spectrum fluorescent lighting on

Discussion

The underlying message in these results is that people believe that lighting is important to the achievement of a healthy and productive life, and in general they prefer the type of lighting that they believe will help them reach that end. Following a summary of the main findings, this section presents the theoretical context—borrowed from classical cognitive psychology research—in support of the need for information from end users in lighting decisions. The final conclusions suggest some specific applications for the findings of this survey.

Hypotheses 1, 2, and 3 form a logical triangle linking importance, knowledge, and desire for control over lighting. People to whom lighting is important are more knowledgeable about lighting, and they desire more control over it (Hypotheses 1 and 3). In this sample, however, knowledge about lighting did not relate to the desire to control lighting. This finding is probably an artifact of the way the two variables were measured: the Knowledge scale was very general, whereas the Desire for Control item was very specific to the setting in which these students studied.

Hypothesis 4 demonstrated a specific relationship between a belief about lighting and an outcome. People prefer bright light if they believe that bright light improves productivity.

Hypotheses 5 and 6 both received support from these data. Natural light is the preference of people who endorse beliefs about negative or harmful effects of fluorescent light; and people who endorse beliefs about the effects of lighting on health also endorse beliefs about the superiority of natural daylight over other light sources. These subjects tended to endorse the type of light that they believed to have beneficial effects on people.

Psychology and Lighting Decisions

Classic psychological investigations of decision making, discussed below, demonstrate how biased results can occur when decisions are made based on inadequate information. It relates well to recent research about facilities managers' lighting decisions, which reveals a need for information about end users' acceptance of new lighting systems.

When facilities managers decide on lighting systems, one important consideration is whether the users are likely to accept what is provided (Conway & Leslie, 1992). Innovative lighting solutions are sometimes passed by because of concern that users will complain about the aesthetics or visibility under the new system or that they will express resistance to change. Building owners might be concerned that their real estate will be more difficult to rent under these circumstances. Although cases are rarely documented in the public domain, designers are no doubt familiar with clients who are not pleased with the

lighting in their space and who come looking for a better solution.

The proactive solution to this problem is twofold: better information about how users respond to lighting and better communication of that information to the people who make decisions about lighting. Conway and Leslie (1992) developed strategies for the latter but did not address the former. Their strategies, which were designed specifically for downstate New York, included the development of seminars for building managers, engineers, and designers to educate them about the technologies that are available for various applications. The education activities would be supported by demonstration sites and a serial publication; in parallel, independent testing and evaluation of new products would develop a trusted data base of information to support lighting decisions.

The participants in Conway and Leslie's (1992) round-table process reported that they might avoid making a risky decision in favor of a new energy-efficient technology because of concern that the occupants might not accept it. The implication is that they lacked information about end users' likely responses; they did not know with certainty how the occupants might react. Cognitive psychology can explain how decisions occur under conditions of inadequate information such as this.

When people must make decisions in areas in which they lack complete information, certain predictable biases occur (Tversky & Kahneman, 1974). Information is given greater weight, for example, if it is recalled more easily (the *availability heuristic*). The more frequent an occurrence, the more likely it is to be remembered, but also the more likely it is to occur again. Availability is an effective rule for decisions involving frequent events.

The more vivid an example or the more recent the event, the more easily it is recalled, regardless of its actual likelihood (Tversky & Kahneman, 1974). This can lead to incorrect judgments because more attention is paid to design failures reported in the press and passed along as office folklore: cases of eyestrain, complaints of headaches, and suspicions about more sinister health effects. We rarely hear from the multitudes who have no problems. One dramatic example—one credible person's testimony that lighting caused severe headaches—can lead others to attribute their own problems to the same source. The lack of correct, objective information about lighting will lead people to form expectations based on what effects come to mind or are imaginable.

Such a bias will also affect interior and lighting designers when they choose a lighting system. Without systematic information about the likelihood of users' acceptance of a new lighting system, everyone involved in the decision will depend

counts for only 4% of the variance in the Y set; the first Y variate explains 7% of the variability in the X set. Although the variate pair has a modest canonical correlation, the overlap of each variate with its opposite set is quite small. The effect is not large; however, the predicted relationship does exist.

⁴ The two sets were significantly correlated (Rao $F = 4.26$; $df = 20$; $p < .001$). The first canonical correlation was .23, and the second was .13. The chi-square statistic associated with all four variate pairs was 84.41 ($df = 20$, $p < .001$). With the first pairs removed, chi-square was 27.05 ($df = 12$, $p < .01$). With the first and second pair removed, chi-square was not statistically significant, indicating that the important linkages

between the two sets are associated with the first two canonical variate pairs.

Although each variate explains a respectable proportion of the variance in its set, the redundancy analysis shows that neither variate explains a large proportion of the variance in the opposite set. The relationship is statistically significant, but the effect is small. The first X variate explains 22% of the variance in its (X) set, and 1.2% of the variance in the Y set (redundancy). The first Y variate accounts for 40% of the total Y variance. The redundancy of the first Y variate with the X set is 2.1%.

The better the designer understands the unspoken beliefs, preferences, and understanding that the client brings to each discussion, the more successfully the designer will be able to communicate with the client.

- simple cognitive performance, mood, and ratings of others. *Journal of Environmental Psychology*, 9, 297-308.
- Butler, D. L., & Biner, P. M. (1987). Preferred lighting levels: Variability among settings, behaviors, and individuals. *Environment and Behavior*, 19, 695-721.
- Conway, K. M., & Leslie, R. P. (1992, February). Hurdling barriers to efficient lighting. *Lighting Design and Application*, 22(2), 26-31.
- Gifford, R., Hine, D. W., & Veitch, J. A. (In press). Meta-analysis as a tool for environment-behavior research, illuminated with the effects of lighting as an example. In G. Moore & R. Marans (Eds.), *Advances in environment, behavior, and design* (Vol. 4). New York: Plenum.
- Goldstick, K. (1990, March). An environmentally conscious workplace. *Lighting Design and Application*, 20(3), 2-5.
- Grosslight, J. (1984). *Light: Effective use of daylight and electric lighting in residential and commercial spaces*. Englewood Cliffs: Prentice-Hall.
- Heerwagen, J. H. (1990). Affective functioning, "light hunger," and room brightness preferences. *Environment and Behavior*, 22, 608-635.
- Heerwagen, J. H., & Heerwagen, D. R. (1986, April). Lighting and psychological comfort. *Lighting Design and Application*, 16(4), 47-51.
- Illuminating Engineering Society of North America (IESNA). (1987). *IES lighting handbook: 1987 application volume*. New York: Author.
- Julian, W. G. (1987). Lighting: An urgent case for a major research effort in architectural science. *Building and Environment*, 22, 155-161.
- Katzev, R. (1992). The impact of energy efficient office lighting strategies on employee satisfaction and productivity. *Environment and Behavior*, 24, 759-778.
- Kerlinger, F. M. (1986). *Foundations of behavioral research* (3rd ed.). New York: Holt, Rinehart, & Winston.
- Moss/Noedel Research. (1990). *Pacific Power lighting acceptance test: An experimental study among 80 Seattle area office workers* (Research Report). Portland: Pacific Power.
- Office lighting, comfort, and productivity—How the workers feel. (1980, July). *Lighting Design and Application*, 10(7), 35-40.
- Ryan, B. J. (1991). Lighting design strategies for energy optimization and human performance. In M. J. Winer & M. Jackson (Eds.), *Energy and environmental strategies for the 1990s* (pp. 531-536). Lilburn, GA: Fairmont Press.
- Smith, F. K., & Bertolone, F. J. (1986). Bringing interiors to light. In F. K. Smith & F. J. Bertolone (Eds.), *Lighting with care* (pp. 161-167). New York: Whitney Library of Design.
- Stone, P. T. (1992). Fluorescent lighting and health. *Lighting Research and Technology*, 24, 55-61.
- Tabachnick, B. G., & Fidell, L. S. (1983). *Using multivariate statistics*. Cambridge, MA: Harper & Row.
- Tregenza, P. R., Romaya, S. M., Dawe, S. P., Heap, L. J., & Tuck, B. (1974). Consistency and variation in preferences for office lighting. *Lighting Research and Technology*, 6, 205-211.
- Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, 185, 1124-1131.
- Veitch, J. A., Gifford, R., & Hine, D. W. (1991). Demand characteristics and full spectrum lighting effects on performance and mood. *Journal of Environmental Psychology*, 11, 87-95.

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Endnotes

¹This correlation is lower than reported by Butler and Biner (1987). They reported strong correlations ($r > .90$) between ratings of the importance of lighting in a setting and the desire to have control over lighting in that same setting. Butler and Biner had data for both lighting importance and desire for control in specific situations, whereas in the present study the importance questions referred to lighting generally and the desire for control item referred to one specific situation. The difference in methods explains the lower correlation size in the present study.

²A slightly better explanation is that this technique is similar to factor analysis in that it attempts to form factors (here called *variables*) that represent the structure of the variables in each set. Variables are calculated in pairs, one from each set. Each variate is a linear combination of the variables in the set, chosen to maximize the correlation between the two linear combinations in that pair. After the highest possible correlation is extracted, the next pair of variates maximizes the correlation of linear combinations of variables using the remaining variance. There may be as many pairs of canonical variates as there are variables in the smaller of the two sets. See Tabachnick and Fidell (1983) for a basic introduction to this technique.

³Rao's F test demonstrated that the two sets were significantly correlated (Rao $F = 6.61$; $df = 18$; $p < .001$). The first canonical correlation was .36. The chi-square statistic for all three canonical correlations included was 116.5 ($df = 18$, $p < .001$); with the first correlation removed, chi-square was not statistically significant. Therefore, only the first canonical variate pair accounts for the significant relationship between the sets of variables.

The criterion for assessing which variables contribute to their respective variates was liberal; variate loadings (correlations of variables with their variates) were considered important if their absolute values were greater than .30. The variate loading patterns show that scores (acceptance of beliefs) on variables B4, B5, B6, and B10 relate to scores on the preference items (preference for light types other than natural light). This supports the hypothesis.

Table 7 also displays the percentage of the variance explained by each variate in their respective sets. It is evident that the Y variate is more successful in explaining the variability in the Y scores (52% explained) than is the X variate in explaining the variability in the X scores (28% explained).

The redundancy values describe the proportion of the variance in the opposite set explained by a given variate. Thus the first X variate ac-