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Veitch, J.A.

NRCC-42469

A version of this paper is published in / Une version de ce document se trouve dans :
Journal of the Illuminating Engineering Society, v. 30, no. 1, 2001, pp. 124-140

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Jennifer A. Veitch, Ph.D.

A version of this paper appeared in the *Journal of the Illuminating Engineering Society, 30*(1), 124-140.

Citation: Veitch, J. A. (2001). Psychological processes influencing lighting quality. *Journal of the Illuminating Engineering Society, 30*(1), 124-140.

Abstract

Veitch and Newsham proposed a behaviorally-based model for lighting quality research, in which individually-based processes mediate the relationships between luminous conditions and such behavioral outcomes as task performance, mood, social behavior, aesthetic judgements and satisfaction. This review paper summarizes the state of knowledge concerning mediating psychological processes: perceived control, attention, environmental appraisal, and affect. These processes were selected because of their relevance to the explanations often given for lighting design choices. More explicit use of theoretically-driven predictions to guide lighting research would result in greater precision in our comprehension of lighting-behavior relationships to form the foundation of empirically-based lighting recommended practice.

Introduction

Surveys of office employees consistently report that lighting is among the more important features of office design and furnishings.[1,2] Likewise, in the professional community of lighting designers and illuminating engineers, there is a long history of speculation that the quality of the luminous environment can influence task performance, comfort, and well-being,[3,4] effects that are fundamentally psychological -- that is, behavioral, in nature. This paper reviews the relevant literature concerning such effects, in an attempt to provide direction for lighting recommended practice and to further lighting quality research.

Stein, Reynolds, and McGuinness once defined lighting quality as "a term used to describe all of the factors in a lighting installation not directly connected with quantity of illumination."[(5, p.887)] Their definition, although flexible enough to be applied to a wide variety of lit environments, offers little guidance concerning how to measure the quality of a lit environment. Veitch and Newsham proposed that lighting quality exists when the luminous conditions support the behavioral needs of individuals in the lit space.[6] This definition has the merit of being measurable, but it only considers the immediate consequences of the luminous conditions on the individuals. More accurately, this definition should be expanded to include architectural and economic considerations, as well as individual well-being (Figure 1). The quality of the lighting in any given installation is determined in the balance of these (sometimes conflicting) dimensions.

One central concern for the lighting community is the means by which we describe the luminous conditions in a space. Guidelines for lighting practice, for example, use photometric criteria to describe the minimum conditions required for good lighting practice (which, one hopes, will also achieve good lighting quality). There is general agreement that luminance, luminance distribution, uniformity, flicker rate, and spectral power distribution describe most of these quantities.[7,8,9] Lighting system characteristics such as individual control, indirect lighting, and the use of daylight are also thought to contribute to good-quality lighting.

Generally speaking, lighting practitioners strive to create luminous conditions that will optimize outcomes for individuals, but often with the intent of optimizing organizational outcomes such as retail sales and the client's bottom-line. These luminous conditions, like other environmental conditions, have effects on people that differ depending on individual characteristics such as age and sensitivity, and they may do so through any of several mechanisms (Figure 2). The mechanisms are theoretical constructs, useful to many scientific disciplines because of their utility for organizing empirical evidence and inductive reasoning into explanatory systems. For convenience, these parallel processes can be divided into two broad categories: psychological processes, which are the focus of this paper, and psychobiological processes such as visibility, photobiology, and arousal. The knowledge of these specific mechanisms that will arise from research will enable precise predictions about expected outcomes, predictions drawn from lighting research and from other topic areas that investigate the same processes. The manner of presentation in Figure 2 is deliberate, in that the lighting conditions are concurrent, the individual and group processes occur simultaneously, and the outcomes occur concurrently. For any individual at any one time, behavior is influenced by many causes. In the review, the sections devoted to each process are structured by the luminous conditions addressed in the body of research identified in our literature search.

The focus of this paper is on the scientific evidence concerning the intervening psychological mechanisms that produce behavioral effects in response to luminous conditions (an earlier attempt is given in Veitch and Newsham[10]). The goal is to describe the state of knowledge about these effects both to serve as initial input to revised recommended practice documents based on the lighting quality framework, and to guide future research. Others, with experience in lighting design, daylighting, luminaire design, and energy use, are better positioned to contribute to the discussion of the other influences on lighting quality diagrammed in Figure 1. (For instance, Loe and Rowlands have opened the discussion on the broader design end energy issues related to achieving good-quality lighting.[11])

This review is organized in terms of the intervening psychological processes that are believed to underlie the lighting-behavior relationship: perceived control, attention, environmental appraisal, and affect. This is not an exhaustive list of possible mechanisms, but a categorization of the principal ones currently in use. This set was chosen because of the frequency with which these mechanisms are invoked as explanations of lighting design choices. When we understand why certain luminous conditions produce the behavioral outcomes we desire, then we will be able to re-create those conditions, and those outcomes, more reliably.

Within the section for each of the four psychological processes are subsections discussing the operation of that process in response to various luminous conditions: luminance/illuminance; uniformity across tasks; luminance distributions within rooms; glare; spectral power distribution; flicker; indirect lighting systems; and, windows and daylighting.[a] These categories generally agree with the luminous conditions described in various recommended practice documents.[7-9] Not every possible luminous condition has been studied in relation to each process, so the number of subsections varies for each psychological process (indeed, in the section on perceived control it was impossible to distinguish between studies on the basis of luminous conditions).

Poor-quality research is a major impediment to understanding. Such criticism of lighting research is long-standing, recognizing its weaknesses in scientific procedure and statistical analysis.[6,12-16] Nonetheless, the existing body of writing about lighting has formed the basis for lighting education and recommended practice documents, Therefore, the review is inclusive, including empirical work from many sources that might be familiar to readers. A detailed critique of each article is beyond the scope of this paper. Instead, major limitations are noted where appropriate, and those conclusions are drawn that were judged supportable from the data provided.

Economic considerations have driven much lighting research, with the result that the vast majority of investigations have considered lighting for offices, with relatively few investigations occurring in other settings. Accordingly, this review focuses on office lighting applications, although studies from other settings are included where their results are relevant. This review is limited to suprathreshold viewing conditions at adaptation levels typical of interiors.

Psychological processes in lighting-behavior relationships

Perceived Control

Among the classic observations in modern psychology is the finding that perceived control can moderate stress reactions. Glass and Singer found that when people were given the opportunity to end an aversive noise (although they did not use it), they did not experience the negative aftereffects on task performance that were observed in people who had not had the opportunity.[17] When control over aversive stimuli is not available, learned helplessness can result, in which individuals suffer emotional, cognitive, and behavioral deficits.[18] Furthermore, belief that the absence of control leads to feelings of unhappiness and powerlessness is widespread.[19,20]

This belief is often used to justify the adoption of individual lighting controls, although few empirical investigations exist to justify this additional expense. Field surveys are consistent in reporting that a sizable percentage of office employees prefer to have some degree of control over their office lighting. Fifty-four per cent reported this in a large North American survey,[1] and 67% in one Midwestern US building.[21] Lighting designers apparently believe that providing individualized lighting controls has far-reaching benefits for occupants.[22]

However, perceived control does not always lead to desirable outcomes. Burger observed that people will decline control when it carries the risk of not achieving a desired goal or if it creates uncomfortable concern with self-presentation.[20] If an expert seems more likely to make the correct choice, or if one risks looking foolish by making the wrong choice, this will be a choice that one does not want. Wineman concurred that in certain situations, control can lead to undesired effects if it requires choices one did not wish to make.[23]

One experiment to date concerning the performance effects of perceived control over lighting obtained results consistent with this pattern. The experiment varied the degree of control available for workplace lighting and examined its effects on task performance. Veitch and Gifford reported that participants who had control over the lighting under which they worked performed more poorly and more slowly on a creativity task than participants who had no control.[24] This control, however, required one to make a decision before the experimenter and another witness, conditions that likely increased self-consciousness. Both having had control and having worked under lighting that one preferred led to the perception of having controlled the workplace lighting. Thus, the perception of control did not influence performance; however, the exercise of control led to a small performance decrement.

Veitch and Newsham [25] gave half of their participants a more direct form of lighting control, allowing them to set the lighting at the start of a day-long session during which participants completed writing, proofreading, and creative writing tasks. Although the participants who had chosen the settings had higher perceived control than others who had not, there were no differences in performance or satisfaction between the groups. They concluded that, given the generally high reported level of satisfaction with the work environment and with the lighting specifically, providing control over the lighting had no additional benefit.

Another possible, but entirely untested, benefit of individual control over lighting could be to reduce or ameliorate the harmful effects of other stressors.[23] Barnes argued that choices about physical environmental conditions can prevent detrimental effects such as feelings of powerlessness and hopelessness.[26] Becker considered that providing individual control over workplace conditions is one component of a quality work environment, in which workers feel competent and satisfied, and in which they perform well, with lower absenteeism and turnover.[27]

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[a] Much of the literature concerning spectral power distribution effects has focused on full-spectrum fluorescent lighting, and has been reviewed elsewhere.[16]

Individual control also has a down side. Becker noted that providing individual control over workplace conditions to employees can be costly, and will be justified only if it provides an economic benefit to the employer or building owner.[28] Moreover, Wineman observed that individual control can also add to job demands, thereby increasing the number and intensity of stressors that can affect performance and health.[23]

Perceived control: summary— Individual lighting controls are, of course, a practical way to accommodate changing task demands, variations in daylight availability, and individual preferences. However, the evidence does not support the notion that perceived control over lighting is inherently beneficial for human well-being or performance, in spaces that have good-quality lighting design. Under demanding conditions or in circumstances leading to concerns about self-presentation, perceived control can lead to undesirable effects. Careful cost-benefit analysis of various lighting control strategies, their effects on perceived control, and their consequences for individual behavior and energy consumption, would help to identify those circumstances in which individualized control over lighting is warranted. Such analyses should also examine the interplay of job demands and corporate culture as moderators of the relationship between perceived control and important outcomes, particularly those known to be sensitive to environmental, job, and social stressors.

Attention

The underlying theory is that certain outcomes can be increased in likelihood by directing the viewer's attention to particular elements in the environment. For example, theatrical lighting designs use spotlights to direct audience attention to the important characters on stage. Because the goal is to make a target stand out by contrast against the background, luminance distributions are the luminous characteristic thought to be most likely to trigger the attention response.

Luminance distributions within rooms— Empirical evidence for the notion that lighting can influence attention is based on two studies that are missing important details about the methods and data, and lacking appropriate statistical tests. Hopkinson and Longmore reported that attention on a vertical visual task was best when the task was locally lit, than when it was lit from general illumination alone.[29] A small, high-brightness light source below the task attracted more short off-task glances, whereas a larger, low-brightness source appeared to be less distracting. The effect, which they called "human phototropism," might also extend to movement, although there is only one study, with tentative results, to support this contention.[30]

LaGiusa and Perney applied this notion to school pupils' attention to instructional material using spot-lighting on the teacher's visual aid. This improved the amount of time spent attending to the task (as judged by an independent observer) and performance on a vocabulary task in a short-term test involving two classrooms.[31] The effect was replicated with a within-subjects design (thereby holding teacher behavior and subject selection effects constant) over a year's exposure to the novel lighting set-up.[32]

Uniformity across tasks— One extension of the attention hypothesis is the notion that task lighting can focus attention on desk work, thereby improving task performance. There is little effect of desktop uniformity on visual performance.[33]. Other investigations found no effect of uniformity on task performance: Illuminance level differences on the desk, associated with varying the light distribution in an office, did not affect (paper-based) clerical task performance in a comparison of 10 different general and local/general combined lighting installations.[34] Nor did varying task document brightness for participants typing text into a VDT influence typing performance.[35] Slater, Perry, and Carter varied the illuminance ratio across an open office with two desks between 0.29 (very nonuniform) and 0.98 (very uniform), but found no effect on a paper-based clerical coding task.[36]

One study has found an effect in which nonuniform desktop illumination improved performance. Adults did complete more arithmetic calculations (on paper) in an office with nonuniform lighting, using incandescent desk lamps, than when the office was lit with uniform fluorescent lighting or very nonuniform colored ("psychedelic") lighting.[37] However, it is not clear that attention was the mechanism. If it were, one would expect that the psychedelic lighting would have been distracting, and would have caused a decrease in performance. Other factors, including preferences for the type of lighting (e.g., Veitch et al. found that people were mistrustful of fluorescent lighting[38]), could account for this result.

Attention: summary— Practical experience from theatre lighting demonstrates that areas of high luminance can attract attention, but it remains unknown whether this mechanism can be used to elicit desirable behaviors in other settings. At the level of whole spaces, it appears possible that luminance distributions can direct attention in useful ways for classroom teaching; however, task lighting on desks does not appear to have this effect. Given the small number of investigations in this domain, a final conclusion is premature.

Environmental Appraisal

Aesthetic judgements concern the interpretation and categorization of what we see; they are far more than only emotional reactions. In this area of research, the first task is to determine the dimensions along which we make aesthetic judgements, and the second is to determine how our aesthetic judgements relate to other responses, such as preferences. Preferences for luminous conditions are discussed below in the Affect section.

Several theoretical models of appraisal and preference exist.[39] One model that relates closely to lighting research is the Kaplans' information-processing model of environmental appraisal. This model posits that the extent to which information is available in the scene is central to our appraisals.[40,41] They believe that humans need to make sense of what they see and to become involved in it. The four dimensions of appraisal in their model are coherence, legibility, mystery and complexity. The first two relate to the presence of information, and the latter two concern the need to be an active interpreter of the information. Preference for scenes generally increases as these qualities increase; however, high levels of one quality can reduce levels of another. For example, a high level of complexity might preclude coherence. Although lighting researchers have not systematically tested the application of this theory to the lit environment, it has parallels with well-known lighting research, which is not surprising given that light provides the stimulus for all visual appraisals of environments. As with attention theory, the majority of relevant research concerns the luminous environment expressed in terms of luminance distributions across space.

Luminance distribution within rooms— Historically, lighting designers have been warned against "doodling with light," to use Waldram's evocative phrase.[42,43] Present-day authors, too, warn against the meaningless use of spotlighting, outside of architectural or functional context.[11] The suggestion that lighting design can convey meaning about the environment is consistent with the Kaplans' theory.[40,41] Empirical evidence supports the idea, although a very limited range of spaces and meanings have as yet been studied.

The classic research program in this area is Flynn's investigations of the appearance of various luminous conditions in conference rooms. Flynn and his colleagues initially obtained ratings on 34 semantic differential scales in response to six lighting configurations, and separate ratings of the similarity or difference between pairs of lighting configurations.[44] They used factor analysis to reduce the semantic differential scales to three interpretable factors: perceptual clarity, evaluative impressions, and spaciousness. Multidimensional scaling was used to identify three dimensions ("lighting modes") that accounted for the judgments of similarity or difference: uniformity, brightness, and overhead/peripheral. Later, they presented a technique for relating the lighting modes to the factors.[45]

Flynn's work was innovative and creative; he was among the first to apply sophisticated psychological techniques and multivariate statistics to lighting research. However, to a contemporary reader, this work suffers from several serious limitations. His sample size was invariably too small for a robust factor analytic solution, which requires 10 people for every one scale[46] (i.e., the initial studies of 34 semantic differential scales would have required a sample size of 340 people for a robust solution, not the 96 reported by Flynn et al.[44]). Moreover, it is unclear how the team developed the initial set of semantic differential scales, or whether they were valid descriptors that were meaningful to the participants. Neither is it clear whether the participants were judging the appearance of the lighting, or the appearance of the room; any confusion about the instructions would add to the random variation in the responses. Finally, and most seriously, this work has never been independently replicated.

Although Flynn et al.[45] clearly intended their work as an interim report, lighting modes and subjective impressions based on this work have been included in subsequent editions of the IESNA Lighting Handbook with little modification.[8,47,48] For example, relaxation is said to be cued by nonuniformity, particularly nonuniform wall lighting. Perceptual clarity is said to be reinforced by higher horizontal luminances in a central location. Spaciousness is cued by uniform lighting and bright walls. These recommendations are taken by many as fact; however, they are based on one published study,[44] which used one setting, a conference room in Pennsylvania. One might reasonably ask on what grounds one may generalize these findings to other settings and other places.

The research group at the Bartlett School of Architecture at University College London undertook a similar series of experiments beginning concurrently with Flynn's work and using similar methodology. In their first paper, Hawkes, Loe and Rowlands reported that perceptions of 18 lighting configurations for a windowless two-person office could be described along two independent dimensions: brightness and interest (non- uniformity).[49] They were unable to obtain an interpretable result in their multidimensional scaling analysis.

The team extended its work to experiments in which lighting was varied in offices both in laboratory mock-up and in the field, and sought to correlate photometric quantities with assessments of lightness and complexity. Rowlands, Loe, McIntosh and Mansfield concluded that the difficulty in this work lies in identifying the areas of the visual field that influence the assessments of the space.[50] They had obtained significant correlations, but the direction of the effects differed across settings. Using luminance mapping instrumentation, the team later found that judgments of lightness and interest in an office space were described by the average luminance and luminance contrast, respectively, within a horizontal band 40 degrees wide and centered at eye height of a seated viewer.[51]

The Bartlett group has obtained similar findings in several separate studies and using a wider range of luminous conditions and settings than Flynn's group; these features strengthen our confidence in the brightness and uniformity dimensions of lighting appraisal. However, their sample size also is too small for the factor analytic techniques applied, leaving open the possibility that the two-factor result is an artifact. Independent replication and further work of this kind, using adequately large sample sizes and techniques (i.e., both exploratory and confirmatory factor analyses with independent samples) is precisely what is needed to advance our understanding of the effects of luminous conditions on aesthetic judgments.

In an attempt to provide such a verification, Veitch and Newsham asked 292 people to rate the appearance of an open-plan office lit with one of nine lighting systems, using 27 semantic differential scales.[52] The results of principal components analysis of these data were not identical to either Flynn's or the Bartlett group's results. The most robust solution was a 3-component solution explaining only 46%of the variance. Visual Attraction, Complexity, and Brightness were the labels given to these three components. Nine scales did not contribute to any of the components. In this case, respondents were directed to judge the appearance of the room, rather than the lighting, in order to prevent bias associated with the knowledge that lighting was the focus of the experiment (which included many other dependent measures). Some authors have argued that this contributes unwanted variance to the ratings and favor explicit instructions to judge the lighting.[53 b]

The Bartlett work suggests that brightness and interest (nonuniformity) are independent constructs, but others seek relationships between them. Perry et al. speculated that nonuniform luminance distributions might lead to the perception of gloom if they cause an adaptation shift from cone- to rod-based retinal processing.[55] However, two research groups have not obtained results consistent with this speculation. Shepherd, Julian and Purcell asked participants in their experiments to rate the appearance of the lit environment using an adjective checklist. The data analysis used non-parametric techniques to identify the adjectives used commonly to describe each lighting scene. Their data indicate that there is a common experience of gloom associated with lighting conditions at low adaptation luminances, particularly when the vertical luminances are low.[56] This finding was replicated and extended to a larger range of luminous conditions.[57] Low surround luminances, mesopic adaptation luminance, high task illuminance with a dim periphery, and conditions that obscure details in the periphery were associated with gloom, but not all nonuniform distributions produced gloom as predicted by Perry et al.

Luminance distribution effects on brightness perception have been obtained by both brightness matching and self-report techniques.[58,59] A small enclosed office with a nonuniform distribution produced by parabolic louvered luminaires was perceived as 5-10% brighter than an identical office with a uniform distribution produced by flat-lensed troffers. The average luminance was the same in both cases, but the variability differed. Reports from the participants about their judgments suggested that it was the contrast between bright and dark portions of the wall that led to the brighter appearance of the nonuniform room.

Environmental appraisal: summary— People use luminance distributions as a basis for judgements about the appearance of a space. The dominant dimensions of these judgments appear to be brightness (or lightness), and interest (variability). Systematic application of appraisal and aesthetics theory from other disciplines would expand our understanding of these judgments. This is of more than theoretical interest because an improved understanding of environmental appraisals would allow us to develop categorizations of luminous conditions for the purposes of describing preferences and for testing hypotheses about information processing in the luminous environment.

Affect

Aesthetic judgments concern the appearance of the space. Satisfaction and preference judgments include an emotional component: how the space makes the viewer feel. Satisfaction is the state of feeling that one’s needs are fulfilled; by implication, conditions that produce satisfaction or comfort are those that one prefers. For some writers, this judgment defines lighting quality.[49,60] Affect is the term used by behavioral scientists to describe emotional responses. In a state of positive affect, one feels pleasant, relaxed, and happy.

Robert Baron, a social and environmental psychologist, is the best-known proponent of the theory that environmental conditions that create a state of positive affect lead to better performance, greater effort, less conflict, and greater willingness to help others.[61] The theory is supported by empirical results using fragrances to elicit positive affect.[62,63] A similar study using illuminance levels and fluorescent lamp types to create various lighting conditions found that positive affect was a likely explanation for performance and cooperation effects, although it was not the only mechanism that could explain the results.[64]

Affect theory has intuitive appeal. For example, people prefer daylight over electric light where it is available, and believe that it is conducive to improved work.[37,65,66] Empirical demonstrations in support of this theory require, first, the demonstration that certain luminous conditions are preferred; and second, that the preferred conditions lead to desired behavioral outcomes such as better task performance, communication, or social behaviors.

[b] This paper[53] was also presented at a CIBSE National Lighting Conference.[54]

We are further ahead at identifying preferred conditions than we are at testing the affect theory, as this review reveals.

Illuminance and luminance— Preferences for illuminance levels are generally higher than the recommended levels, although preferences vary widely between individuals, settings, and tasks. One important difference is that illuminance preferences exceed recommended levels most often in field studies or experiments with a high degree of similarity to real settings; the investigations in which lower illuminances have been preferred are generally laboratory experiments with a limited range of experimental conditions.

The general statement that people prefer higher illuminances than recommended practice levels crosses international differences in illuminance practices. Researchers in the Netherlands, Sweden, United Kingdom, United States, and Canada have observed this, in studies covering the period 1969-1995.[67,69-74c] One exception to this pattern is a pilot study involving French office workers, in which illuminance preferences were consistent with recommended practice.[76] In the US, Kimmel and Blasdel found that student ratings of library lighting installations showed a preference of 425 lx, which was lower than they expected.[77]

At illuminance levels below 400 lx, there are inconsistent relationships between illuminance and preference. Nelson et al. found that their highest illuminance level, 320 lx, was lower than their male participants' preferred level for office work, but there were no effects of illuminance on other mood or satisfaction measures.[78d] In a separate experiment, Nelson et al. found that increasing illuminance from 100 to 300 lx decreased men's scores on three mood measures (concentration, activation, and good mood), but increased women's scores on these measures.[80] The failure to replicate the finding that men preferred higher illuminance is puzzling. In neither experiment were preferred luminous conditions associated with improved performance on any measure. Horst et al. found that ratings of the ease of working, desire to work under the lighting condition, and comfort, increased from 10 to 200 lx illuminance, but remained stable from 200-800 lx.[81]

There is considerable individual variability in illuminance preferences. Tregenza et al. observed that individuals consistently chose the same desktop illuminance levels, but the variance over all participants was high.[83] Heerwagen found that people with Seasonal Affective Disorder or the milder, subsyndromal, form of this mood disorder consistently preferred higher room illuminance levels than matched, normal controls.[84] Begemann, Beld, and Tenner reported that two male participants whose illuminance preferences were observed over a year showed a consistent difference in the preferred level, one preferring a very low level and one a high level.[85] This sample size is too small for any generalization, but the consistent pattern reminds us that individual differences are not random response biases. Halonen and Lehtovaara also found that individuals differ widely in their illuminance preferences. These differences are great enough that it would be impossible to develop a single algorithm for daylight-linked dimming that would satisfy all occupants.[69]

Leslie and Hartleb found a trend that suggests possible sex differences in illuminance preference (the few female participants preferred much lower levels than the male participants).[70] However, Butler and Biner found sex differences in preferred light level only for two (of 43) behaviors: washing dishes and leaving a parking garage.[86] Knez found in one experiment that females rated the lighting as more intense and glaring than males, regardless of the actual conditions; however, this finding did not replicate in a second experiment with lamps of different CRI.[82]

The literature is equivocal concerning age differences in illuminance preference. Boyce did not find that age influenced illuminance preferences.[71] Older clerical workers, however, did show stronger preferences for higher illuminance than younger ones.[74] Age-related increases in illuminance preference would be consistent with known age-related decrements in vision, but it may be that the overall preference for higher illuminance masks this effect. Also, vision correction with spectacles would make increases in illuminance unnecessary.

Task type influences illuminance preference. Lower illuminance levels are preferred for offices where VDTs are used than are preferred for paper-based, horizontal tasks.[87] Visually demanding tasks (e.g., reading, studying) have higher preferred light levels, as rated on a relative (abstract) scale, than tasks that are intimate or relaxing (talking with a friend, listening to music).[86] Biner et al. found that lighting level preferences, rated on an abstract scale of brightness, vary with the social situation as well as the task demands, particularly for tasks with relatively few visual demands.[88]

Uniformity across tasks— Desktop illuminance uniformity became a more important issue with the change from general lighting schemes to combinations of ambient and task lighting. The acceptability of such systems was of great interest. Boyce's 1979 evaluation of various types of then-current task lighting suggested that the acceptable

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[c] For detailed information about the protocol in Ref. 67, consult Aarts' Master's thesis. [68] The investigation reported in Ref. 74 was also written up and published by Barnaby.[75]

[d] Thermal comfort results from this investigation were reported by Nelson, Nilsson, & Hopkins.[79]

installations would provide a uniform distribution over a large area of the desk surface.[89]

However, more recent data suggests that illuminance uniformity across the desk is not an inflexible requirement. Slater and Boyce asked participants to rate the evenness of the lighting, its acceptability, and its comfort, in relation to various illuminance ratios across a desktop task (task performance was also measured, but did not vary in relation to uniformity).[90] They concluded that for tasks that are primarily in the center of the desk, illuminance ratios as low as 0.5 would be acceptable for most people. Similarly, rankings of five luminous conditions with several measures of visual comfort were not related to the illuminance uniformity across the desk surface.[91] Rather, the luminous conditions of all the work surfaces, vertical and horizontal, were important. Bright surfaces without excessive glare were most highly rated. Veitch and Newsham found that participants preferred task/ambient lighting installations, which were the least uniform across the desk surface, giving them higher ratings for lighting quality and satisfaction, and lower ratings for glare.[52]

Luminance distributions within rooms— The brightness of vertical surfaces appears to be key to satisfaction. Collins et al. concluded that the low ratings given by office occupants to the combination of indirect furniture-mounted fluorescent luminaires with undershelf task lamps was related to the high task illuminance and low peripheral brightness of the workstation.[92] When the same systems furniture was lit with a direct system, vertical luminances were higher and so was satisfaction. Similarly, a lighting retrofit that increased the luminances of upper walls and the overall average wall luminance met with increased satisfaction with the office lighting.[93]

People prefer brighter walls to dark ones, provided the brighter walls do not create a glare source. The question is, how high should the vertical surface luminance be? Ooyen, Weijgert, and Begemann studied preferences for various luminance distributions at a fixed task illuminance of 750 lx by varying the reflectance of room surfaces.[94][e] They concluded that wall luminance is the principal contributor to the experience of the room, with wall luminance preferences varying depending on the type of task (reading paper, conference, or VDT work). Wall luminance, of course, largely determines the vertical illuminance at the eye of a person looking at the wall. Thus, these findings are consistent with those of Iwata et al., who reported that both horizontal illuminance and vertical illuminance at the eye predicted visual comfort judgments.[95]

Jointly, the Quality of the Visual Environment (QVE) committee of the Illuminating Engineering Society of North America and the Metrics of Quality (MOQ) committee of the International Association of Lighting Designers have conducted a series of pilot studies on preferences for various luminous conditions. These studies all share a source of bias in that lighting experts acted as participants. The expert opinions are important, however, for their consensus results in recommended practice documents. All three pilot experiments thus far have related room surface luminance to judgments of preference, acceptability, and overall lighting quality in offices.

Miller reported an informal experiment in which conference attendees rated their opinions of five scenes in simulated offices.[3] The most-preferred scene had approximately equal amounts of lighting energy directed at the walls and working plane. The task illuminance of that scene was 387 lx and the ratio of maximum to minimum wall luminance was 3:1 (the range over all scenes was 2:1 to 4.5:1, and illuminance ranged from 108 to 646 lx).

This pilot study paved the way for a more detailed examination of ceiling and wall luminances in relation to acceptability judgments.[97] In that study, for direct/indirect luminaires, higher desktop illuminance was preferred (range 300-700 lx) and ceiling:wall luminance ratios between 1:3 and 3:1 were preferred over the extremes of 1:5 and 5:1. For low-brightness recessed parabolic louvered luminaires, the participants preferred having some light on the walls: ceiling:wall luminance ratios of 1:3 and 1:5 were preferred over 1:1. In a re-analysis of the data combining all lighting systems, they found that the best predictor of acceptability judgments was the average of the wall and ceiling luminance, which they called <u>volumetric brightness</u>. Higher values predicted greater acceptability.

The QVE/MOQ committee followed this with an investigation of the effects of varying lighting systems in a realistic manner in an open-plan office with VDTs.[98] The results did not precisely replicate Miller et al.,[97] but were consistent with it. The average luminance of the partition in front of the seated viewer and of reflected luminaire images in the VDT screen predicted lighting quality judgments. The brighter the partition and the darker the reflected images, the higher the lighting quality judgment.

The luminance distribution between the task and its distant background, and horizontal illuminance ratios across a space, have become more important with the advent of task/ambient lighting designs. Bean and Hopkins found that the highest percentage of raters were satisfied with task lighting when the illuminances for the task and background (ambient) lighting were equal.[99] They recommended that task:background illuminance ratios be close to 1:1. However, McKennan and Parry found that nonuniform distributions can be acceptable.[34] All the installations, both localized (directed from the ceiling to the desk) and local (task lamps) lighting, were rated as satisfactory, even

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[e] This paper[94] was also presented at a CIBSE National Lighting Conference. [95]

though some of these systems produced illuminance ratios for desk surfaces and wall:task that were much lower than the recommended practice.

Nonuniform distributions from task/ambient combinations can contribute to the creation of environments that one would describe as comfortable, particularly for VDT work.[52,100] The degree of acceptable nonuniformity remains undetermined. The relationship appears to depend on the level of overall illuminance. Slater et al. found that illuminance ratios as low as 0.6 between desks in an open office were acceptable when room illuminance was high (730 lx), but the lower limit of acceptable illuminance uniformity between desks for lower illuminance (350 lx) was 0.7.[36] This suggests that at low illuminance, people want more uniformity.

This result is consistent with Tabuchi, Matsushima, and Nakamura, who asked for settings of participants' preferred ambient illuminance and the lower limit of acceptable ambient illuminance for a range of task illuminance levels.[101] The preferred levels were much higher than the lower limits. For task illuminances up to 500 lux, participants preferred equal levels of task and ambient illuminance. Above 500 lx, the optimal conditions consisted of ambient illuminance slightly lower than the task illuminance. The participants' lower limits of acceptability, however, showed that conditions with ambient illuminance much lower than the task illuminance can be acceptable.

Understanding the structure of environmental appraisals can help us to describe the luminous conditions that are preferred; thus, the environmental appraisal and affect processes are intertwined. Judgments that a space appears interesting or pleasant are associated with nonuniform luminance distributions in the field of view. VDT operators preferred having a spot light to highlight a painting on the wall beyond the VDT screen, over the same wall with uniform illumination.[35] Yorks and Ginthner found that visitors to a mock office preferred to have a bright wall in front of the desk, and tended to move farther into the room towards the brighter wall (although this finding is questionable, given the small sample size and unusual data analysis).[102] Tregenza et al. found that preferred wall:desk illuminance ratios were different for the front, rear, left and right walls.[83] Their participants preferred a brighter wall behind the desk.

More systematically, the Bartlett research group found that nonuniform luminance distributions were preferred over more uniform ones. Hawkes et al. found that 8 configurations with diffuse light sources were all rated as uninteresting; 10 configurations with one or more focused source were on the interesting side of neutral.[48] They speculated that this related to the presence of boundaries that created contours of light and dark, but noted the difficulty of isolating a single physical measure that predicted the subjective judgments. Loe, Rowlands, and Watson found that moderately nonuniform wall lighting was preferred for viewing paintings in a simulated art gallery.[103] In 1994, Loe et al. determined that ratings of interest and pleasantness were related to the log of the maximum:minimum luminance ratio in a 40-degree band centered at the eye height of a seated viewer.[51] The higher this value, the more interesting and pleasant the space appeared.

To extract the preferred luminance ratios from the literature is a difficult task. Each team has chosen a different set of photometric measurements in the absence of a common protocol for describing the luminous environment. Recalculations have been made to convert some of the published values to common ratios. These are summarized in Table 1. Several reports included illuminance values or illuminance ratios, but these could not be converted to luminances without the associated reflectance values. It is clear from the table that generalizations about preferred luminance values are difficult to make based on current knowledge. Variability and interest appear to be desired, but to what degree, and where in the field of view, remain poorly understood.[f]

Glare— It seems reasonable to assume that glare sources that cause discomfort are unlikely to be preferred; indeed, this is the premise underlying most glare indices, including VCP.[g] One would expect that preferred luminous conditions would lack direct glare from luminaires, veiling reflections, and reflected luminaire images; however, some luminance contrast is clearly also preferred. The ideal balance between luminance distributions that are interesting, and prevention of glare, is unknown.

Veitch et al. found that overall ratings of lighting quality were inversely related to the brightness of reflected images in VDT screens: the brighter the reflected image, the lower the rating of lighting quality.[98] Lighting systems that produced reflected images were rated more poorly than those that did not. Veitch and Newsham reported greater satisfaction and lower ratings of glare for those lighting installations (task/ambient combinations and parabolic louvered systems) that had lower ceiling luminance and lower luminance of reflected luminaire images.[52]

A systematic model of this effect relates disturbance ratings to the luminance modulation of the reflected

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[f] Temporal variability might also be preferred over static lighting. Aldworth and Bridgers did not find systematic effects on performance of a clerical task, but did find that ratings of room appearance were better when the lighting varied during the working session than when it was unchanging.[104]

[g] For a more detailed discussion of VCP and glare prediction, see Veitch and Newsham.[6]

image, the effect of ambient light on the display, and the degree to which the display blurs reflected images (a function of screen specularity).[105] The model predicts greater disturbance when there are brighter reflected images, when ambient light reduces contrast, and when the reflected images are sharp. This model awaits independent validation.

Spectral power distribution— In a series of rigorous experiments, Baron et al. tested the hypothesis that lighting conditions that produce positive affect will influence cognitive task performance and social behaviors.[64] Their most preferred condition used warm-white fluorescent lamps at 150 lx (versus a variety of other lamp types, all at either 150 or 1500 lx). The results did not clearly demonstrate that the lighting conditions (combinations of illuminance and lamp spectral power distribution) caused positive affect, but the pattern of results over the three experiments was consistent with other research concerning the effects of positive affect on behavior. They concluded that further research is needed to demonstrate clearly that positive affect mediates lighting-behavior relationships, and to identify the luminous conditions that create positive affect.

Knez also examined lamp type (cool-white and warm-white fluorescent lamps) and illuminance level (300 lx and 1500 lx).[82] Participants clearly discriminated between illuminance levels, reporting that the brighter condition was brighter, more glaring, less dim, less soft, and more intense; however, illuminance levels were not associated with changes in positive affect in his sample of Swedish adults. Although there were no main effects of lamp type or illuminance on mood or cognitive tasks, there were interactions of lamp type and gender. In Experiment 1 (in which the lamps were high-CRI) there was a significant interaction of lamp type x gender on negative affect. In Experiment 2 (with low-CRI versions of the two lamp types), there was a significant interaction of lamp type x gender on positive affect, an orthogonal dimension to negative affect. Various two- and three-way interactions of lamp type, illuminance, and gender were reported for the cognitive tasks, but none of them were the same for both experiments 1 and 2. Knez interpreted the pattern as being consistent with the notion that affect mediates the behavioural response to lighting, in that the best performance for each gender group appeared to be in the luminous conditions that produced the best affective response (least negative or most positive). However, these conditions did not clearly favour any particular lamp type or illuminance level of those tested. (See Ref 16 for more detail concerning SPD effects on mood and other outcomes.)

Indirect lighting systems— Several investigations have found that lighting systems with an indirect component are preferred over direct-only systems. Both Yearout and Konz[35] and Harvey et al.[106] found that indirect systems were preferred over parabolic louvered systems for VDT work. Mean ratings on seven semantic differential ratings of the lighting system consistently favored lensed-indirect over parabolic louvered lighting, as did ratings of overall satisfaction with lighting.[107] There also exist successful case studies in which energy-efficient indirect lighting systems using high-intensity-discharge sources were installed and judged by occupants to be improvements over the previous lighting system.[108,109]

Katzev compared performance and preferences under four lighting systems in single-occupant enclosed offices with VDTs, obtaining confusing results.[110] Depending on the method of evaluation, either energy-efficient parabolic luminaires or recessed direct-indirect luminaires were the preferred lighting for enclosed offices. The recessed lensed system was always the least preferred of the four (the fourth was a less-energy-efficient parabolic louvered luminaire). Acceptable illuminance settings were also highest for the recessed lensed system; people preferred lower illuminance levels for the other three systems. The encouraging thing about this finding is that people can find energy-efficient lighting not only acceptable, but preferable to conventional, lensed troffers.

The QVE/MOQ joint committee found similar results in their comparison of lighting quality ratings for suspended direct/indirect, furniture-mounted indirect + compact fluorescent task lighting, recessed parabolic troffers, and recessed lensed troffers.[98] Overall, the two systems with an indirect component were preferred over the direct-only systems. Of the two direct-only systems, the parabolic louvered system was preferred. The furniture-mounted indirect system was preferred over the suspended direct/indirect system, but there was reason to believe that this was an artifact of the particular suspended system, and not typical of all such systems.

One exception to this pattern is Collins et al., who found that the least-preferred of all systems in their field study was the combination of furniture-mounted indirect lighting and undershelf task lighting.[92] However, closer analysis of these data revealed that this was partly an artifact of the particular installation. It featured very high task illuminance, but low overall room luminance; the extremes of bright and dark in this case may have been too great. Veitch et al. found that lighting designers rated the combination of furniture-mounted indirect lighting and task lighting as highest in lighting quality.[98]

There is intense interest in the relationship between lighting and productivity because the economic case for lighting expenditures is easy to make if a purported lighting improvement leads to more work or fewer errors. For example, Kiernan argued that lighting improvements are economically wise investments, citing unpublished work in which internal productivity measures improved dramatically following a change from direct to indirect lighting at a postal station in Nevada.[111] Scientific evidence for performance effects in preferred lighting conditions is limited to date, but is consistent with the affect theory. Preferred conditions generally have been associated with better task performance, although some studies have been limited to self-rated task performance measures, which have suspect validity and reliability. Employees are likely to be biased about their own work, and are subject to expectancy biases depending on their reactions to the environmental change and other workplace conditions.

Hedge et al. conducted a field study of suspended lensed-indirect and parabolic louvered lighting systems which were installed as part of a renovation in a building that originally was lit with recessed, lensed troffers.[107] The self-reported productivity data showed that office workers whose spaces received the lensed-indirect systems (which were preferred) believed that their productivity had increased by 2.5% after the renovation. For the parabolic-louvered group, there was no change in self-reported productivity.

Despite many attempts, few laboratory investigations have found statistically significant effects of lighting system type on office work performance, either of computer-based or paper-based tasks. The most common problem with these studies is inadequate sample size to detect a small- or medium-sized effect. Bennett compared louvered and lensed direct luminaires, and a combination of indirect luminaires with task lighting, and found no effects on VDT number-checking and form-completing tasks and on a perceptual reasoning task on paper.[111] Harvey et al. found no effect of lighting system (parabolic direct, lensed direct/indirect, or indirect-only) on VDT-based data checking.[106] Similarly, typing performance did not differ for VDT operators under direct or direct + indirect lighting.[35] Katzev's performance results were mixed, as were the preference results discussed above.[110] Reading comprehension was best in the office with the direct/indirect luminaires, but typing performance was worst in that office; there were no other statistically significant effects.

Veitch and Newsham had hypothesized that indirect and direct/indirect systems would lead to better performance because lighting designers believe them to produce higher lighting quality, but their data did not support this conclusion.[52] Parabolic-louvered direct luminaires did produce better performance than recessed lensed troffers, but performance under the indirect and direct/indirect systems was neither better nor worse than these. They speculated that differences within the set of indirect and direct/indirect systems were greater than the differences within the sets of parabolic-louvered and recessed-lensed troffers, weakening the statistical power of the comparison in their experiment.

Windows and daylighting— Although people believe that daylight is beneficial, the importance of having access to windows is variable. Butler and Biner found that the nature of the setting determined window preference for university students; no windows was the most common preference stated for lecture halls, public washrooms, and computer workrooms, whereas large windows were preferred for family rooms, dormitory bedrooms, and libraries.[113] Field surveys in schools and offices generally report that people prefer to have a window.[114,115] For example, in one survey, people in windowed offices rated their offices more favorably (more spacious, better air circulation, more humid, cooler) that those without windows.[93]

Window preferences are complex, which may account for the contradictions in various recommendations for window size and placement.[114,115] Research in this field has frequently used scale models, but the results thus obtained might not be applicable in real settings. It is also difficult to control in field surveys for such factors as job classification, gender, window orientation, or view, which can influence judgments of the acceptability of the space.

The tentative understanding that can be drawn with present knowledge emphasizes view as much as lighting. Office occupants who have access to a window report that having access is less important than people who lack access to a window; perhaps people who have a window take it for granted.[65,116] Access to a window is important to provide a view outdoors for temporal information, which appears to be more important than for providing natural daylight.[113] Preferences for window size depend both on the nature of the view (larger windows are preferred for more beautiful views), on the requirement for a minimum acceptable lighting level, and on the size and shape of the room.[117]

Preferred luminous conditions in daylit spaces vary widely across individuals and in relation to the proportion of daylight in the space.[69,85] One generalization that may be drawn from both investigations is that individuals will use electric lighting to increase the luminance at the end of the space away from the window, even if this adds additional, unnecessary light to the work surface near the window. Without daylight, participants in the short-term study by Halonen and Lehtovaara preferred a mean task:wall luminance ratio of about 3:1, which is in line with current recommended practice; but with daylight, the variability in preferred luminance ratios increased dramatically.[69]

Affect: summary— Demonstrations of affect theory require information about lighting preferences and their effects on performance and other behaviors. As the length of this section attests, there have been many attempts to determine which luminous conditions people prefer. Although it appears that people prefer bright vertical surfaces and luminous conditions that are sufficiently nonuniform to be characterized as "interesting", there is no consensus on the luminance values or distributions that are preferred. Predictive models for discomfort associated with glare exist, but there is little guidance for the degree of luminance contrast that might be positively desired as contributing to interest. Indirect and direct/indirect lighting systems appear to be preferable to direct-only systems, but not conclusively so.

The state of the evidence for performance effects associated with preferred luminous conditions is preliminary. Experimental attempts to manipulate affect provide tantalizing hints that positive affect might mediate lighting-behavior relationships. However, more convincing tests of the theory would be possible using lighting conditions known to differ in the degree of positive affect they elicit.

Conclusions

Veitch and Newsham concluded that previous attempts to model or to predict lighting quality from luminous conditions have failed because of poor science, and presented a schematic model as a guide to scientists.[6] This paper expands on that model with a summary of relevant research results, organized by theoretical psychological processes thought to mediate lighting-behavior relationships.

Progress in understanding lighting effects on human behavior and well-being will move more quickly if scientists make measurable, theoretically-based predictions about what they expect to observe, and if they select their luminous conditions to provide a meaningful test of their predictions. Relevant theory from other sciences should be incorporated, as has been argued.[6]

Imprecise use of theories about psychological processes has likely contributed more heat than light in our literature. Perceived control has a strong basis in the psychological literature, but installing complex individual controls without a better understanding of where they would be useful is a strategy that could backfire. Attention is popularly thought to be a function of luminance distributions, but the few studies currently in print are not conclusive.

Environmental appraisal and affect are interconnected theories. One, appraisal, analyzes the meanings we extract from scenes we view. The other concerns our emotional response to them and predicts desirable behavioral responses if that response is positive. Both are in embryonic states of development. In particular, we lack replicable knowledge about the structure of interpretations of luminous conditions -- how many dimensions are there, and what are they? Nor do we know which conditions will create the positive affective state that appears likely to lead to the outcomes desired by individuals and their employers: cooperation, creativity, improved work performance. A better understanding of appraisal in the lit environment would serve as a starting point for the selection of luminous conditions for a test of affect theory and, ultimately, to better predictions about the size of lighting effects on these important outcomes.

We need to pay special attention to controversies that will arise when comparing predictions made under differing models. For example, uniformity recommendations, which are based on visual performance models, advocate near-unity luminance or illuminance ratios.[7,8,9] The literature reviewed here, however, suggests that nonuniformity does not degrade visual performance and is acceptable, provided that the task is lit sufficiently. Nonuniformity across a room appears to be preferable to uniformity because it creates interest and can highlight important information. However, there is probably a limit to acceptable uniformity. For example, at what point does nonuniformity switch from being an interesting contrast to a glare source?

Researchers have a responsibility to undertake this work. Boyce argued that more, better lighting research was needed because “past practice was excessive and we can’t afford the energy for that any more,” [12, p. 413] but in the 16-plus years since he wrote those lines there has been strikingly little progress towards resolving long-standing questions about the behavioral effects of lighting. The consensus-based lighting recommendations process is notorious for its weak link to the research literature.[118,119] This is unsurprising, given the poor state of the existing knowledge. We can do better; and, we can take heart from recent laboratory and field demonstrations that lighting can be both energy-efficient and achieve high quality in terms of human well-being.

Such research will not take away from the creativity and importance of lighting designers and applications specialists. The research itself will not the answer the question, “How can we provide good lighting quality?” The “how” depends on the lighting systems available (including daylighting), energy-use considerations, and the budget. It requires an integration of lighting and architecture, so that the patterns of luminances are not only within some acceptable range (set out from research results), but meaningful in the space. The reflectances and finishes of walls, ceilings, floors, window treatments, and furnishings are also part of this answer. These matters lie in the domain of the lighting practitioner, whose skills will be increasingly needed to determine how best to achieve the luminous conditions known to contribute to human well-being.

Acknowledgements

This paper is based in part on an earlier work entitled "Determinants of Lighting Quality II: Research and Recommendations", by J. A. Veitch and G. R. Newsham, which was presented at the 104th Annual Convention of the American Psychological Association, Toronto, Canada, August 9-13, 1996.[120] I would like to thank Peter Boyce, Warren Julian, Stuart Kaye, David Loe, Guy Newsham, Carlla Smith, Dale Tiller, and four anonymous reviewers for their comments on earlier drafts. The preparation of this paper was supported by the Canadian Electrical Association (Agreement No. 9433 U 1059), Natural Resources Canada, the Panel on Energy Research and Development, and the National Research Council of Canada (NRC), as part of the NRC project "Experimental Investigations of Lighting Quality, Preferences, and Control Effects on Task Performance and Energy Efficiency".

References

1. Office lighting, comfort, and productivity - How the workers feel. (1980, July). *Lighting Design + Application, 10*(7), pp. 35-40.
2. Spreckelmeyer, K. (1993). Office relocation and environmental change: A case study. *Environment and Behavior, 25*, 181-204.
3. Miller, N. (1994, March). Pilot study reveals quality results. *Lighting Design & Application, 24*(3), pp. 19-21.
4. Wagner, W. F. (1985, April). Round Table: Lighting — an art supported by a technology. *Architectural Record, 173*(4), pp. 156-163.
5. Stein, B., Reynolds, J. S., & McGuinness, W. J. (1986). *Mechanical and electrical equipment for buildings* (7th ed.). New York: Wiley.
6. Veitch, J. A., & Newsham, G. R. (1998). Determinants of lighting quality I: State of the science. *Journal of the Illuminating Engineering Society, 27*(1), 92-106.
7. Chartered Institution of Building Services Engineers. (1994). *Code for interior lighting*. London, UK: CIBSE.
8. Rea, M. S. (Ed.). (1993). *Lighting handbook* (8th ed.). New York: Illuminating Engineering Society of North America.
9. Swedish National Board for Industrial and Technical Development (NUTEK). (1994). *Lighting design requirements: Office lighting* (S-117 86). Stockholm, Sweden: Swedish National Board for Industrial and Technical Development, Department of Energy Efficiency.
10. Veitch, J. A., & Newsham, G. R. (1995). Quantifying lighting quality based on experimental investigations of end user performance and preference. In *Proceedings of Right Light Three, The Third European Conference on Energy-Efficient Lighting, Newcastle-upon-Tyne, England, June 18-21, 1995* (Vol. 1, pp. 119-127). Newcastle-upon-Tyne, UK: Northern Electric PLC.
11. Loe, D. L., & Rowlands, E. (1996). The art and science of lighting: A strategy for lighting design. *Lighting Research and Technology, 28,* 153-164.
12. Boyce, P. R. (1981). *Human factors in lighting*. London: Applied Science Publishers.
13. Gifford, R. (1994). Scientific evidence for claims about full-spectrum lamps: Past and future. In J. A. Veitch (Ed.)., *Full-spectrum lighting effects on performance, mood, and health* (IRC Internal Report No. 659, pp. 37-46). Ottawa, ON: National Research Council of Canada, Institute for Research in Construction.
14. Kaye, S. M. (1992, October). The psychology of lighting. *Lighting, 6*(5), pp. 26-28, 36.
15. Tiller, D. K. (1990). Towards a deeper understanding of psychological effects of lighting. *Journal of the Illuminating Engineering Society, 19*(2), 59-65.
16. Veitch, J. A., & McColl. S. L. (1994). Full-spectrum fluorescent lighting effects on people: A critical review. In J. A. Veitch (Ed.), *Full-spectrum lighting effects on performance, mood, and health* (IRC-IR-659, pp. 53-111). Ottawa, ON: National Research Council of Canada, Institute for Research in Construction.
17. Glass, D. C., & Singer, J. E. (1972). *Urban stress*. New York: Academic Press.
18. Seligman, M. E. P. (1974). Depression and learned helplessness. In R. J. Friedman & M. M. Katz (Eds.), *The psychology of depression: Contemporary theory and research* (pp. 83-113). Washington, D.C.: Winston-Wiley

19. Averill, J. R. (1973). Personal control over aversive stimuli and its relationship to stress. *Psychological Bulletin*, *80*, 286-303.
20. Burger, J. M. (1989). Negative responses to increases in perceived personal control. *Journal of Personality and Social Psychology*, *56*, 246-256.
21. Ne'eman, E., Sweitzer, G., & Vine, E. (1984). Office worker response to lighting and daylighting issues in workspace environments: A pilot survey. *Energy and Buildings, 6*, 159-171.
22. Simpson, M. D. (1990). A flexible approach to lighting design. *Proceedings of the CIBSE National Lighting Conference Cambridge, England 8-11 April 1990* (pp. 182-189). London, UK: Chartered Institution of Building Services Engineers.
23. Wineman, J. D. (1982). The office environment as a source of stress. In G. W. Evans (Ed.)., *Environmental stress* (pp. 256-285). New York: Cambridge University Press.
24. Veitch, J. A., & Gifford, R. (1996). Choice, perceived control, and performance decrements in the physical environment. *Journal of Environmental Psychology, 16,* 269-276.
25. Veitch, J. A., & Newsham, G. R. (2000). Exercised control, lighting choices, and energy use: An office simulation experiment. *Journal of Environmental Psychology, 20,* 219-237.
26. Barnes, R. D. (1981). Perceived freedom and control in the built environment. In J. H. Harvey (Ed.), *Cognition, social behavior, and the environment* (pp. 409-422). Hillsdale, NJ: Erlbaum.
27. Becker, F. D. (1986). Quality of work environment (QWE): Effects on office workers. *Prevention in Human Services, 4*, 35-57.
28. Becker, F. D. (1991). Workplace planning, design, and management. In E. H. Zube & G. T. Moore (Eds.), *Advances in environment, behavior, and design* (Vol. 3, pp. 115-151). New York: Plenum.
29. Hopkinson, R. G., & Longmore, J. (1959). Attention and distraction in the lighting of work-places. *Ergonomics, 2*, 321-334.
30. Taylor, L. H., & Sucov, E. W. (1974, April). The movement of people toward lights. *Journal of the Illuminating Engineering Society, 3*, 237-241.
31. LaGiusa, F. F., & Perney, L. R. (1973, May). Brightness patterns influence attention spans. *Lighting Design + Application, 3*(5), pp. 26-30.
32. LaGiusa, F. F., & Perney L. R. (1974, April). Further studies on the effects of brightness variations on attention span in a learning environment. *Journal of the Illuminating Engineering Society, 3*, 249-252.
33. Rea, M. S., Ouellette, M. J., & Tiller, D. K. (1990). The effects of luminous surroundings on visual performance, pupil size, and human preference. *Journal of the Illuminating Engineering Society, 19*(2) 45-58.
34. McKennan, G. T., & Parry, C. M. (1984). An investigation of task lighting for offices. *Lighting Research and Technology, 16*, 171-186.
35. Yearout, R., & Konz, S. (1989). Visual display unit workstation lighting. *International Journal of Industrial Ergonomics, 3*, 265-273.
36. Slater, A. I., Perry, M. J., & Carter, D. J. (1993). Illuminance differences between desks: Limits of acceptability. *Lighting Research and Technology, 25*, 91-103.
37. Taylor, L .H., Sucov, E. W., & Shaffer, D. H. (1975, May). Office lighting and performance. *Lighting Design and Application, 5*(5), pp. 30-36.
38. Veitch, J. A., Hine, D. W., & Gifford, R. (1993). End users' knowledge, preferences, and beliefs for lighting. *Journal of Interior Design, 19*(2), 15-26.
39. Gifford, R. (1997). *Environmental psychology: Principles and practice* (2nd ed.). Boston: Allyn & Bacon.
40. Kaplan, S. (1987). Aesthetics, affect, and cognition: Environmental preference from an evolutionary perspective. *Environment and Behavior, 19,* 2-32.
41. Kaplan, S., & Kaplan, R. (1982). *Cognition and environment: Functioning in an uncertain world*. New York: Praeger.
42. Waldram, J. M. (1954). Studies in interior lighting. *Transactions of the Illuminating Engineering Society (U.K.), 19*(4): 95-133.
43. Waldram, J. M. (1958). Design of the visual field as a routine method. *Transactions of the Illuminating Engineering Society (U.K.), 23*(2): 113-123.
44. Flynn, J. E., Spencer, T. J., Martyniuk, O., & Hendrick, C. (1973). Interim study of procedures for investigating the effect of light on impression and behavior. *Journal of the Illuminating Engineering Society, 3*(2), 87-94.

45. Flynn, J. E., Hendrick, C., Spencer, T., & Martyniuk, O. (1979, January). A guide to methodology procedures for measuring subjective impressions in lighting. *Journal of the Illuminating Engineering Society, 8*, 95-110.
46. Kerlinger, F. N. (1986). *Foundations of behavioral research* (3rd ed.). New York: Holt, Rinehart, & Winston.
47. Kaufman, J. E., & Christensen, J. F. (Eds.) (1987). *IES Lighting Handbook: 1987 Application Volume*. New York: Illuminating Engineering Society of North America.
48. Kaufman, J. E., & Haynes, H. (Eds.) (1981). *IES Lighting Handbook: 1981 Application Volume*. New York: Illuminating Engineering Society of North America.
49. Hawkes, R. J., Loe, D. L., & Rowlands, E. (1979). A note towards the understanding of lighting quality. *Journal of the Illuminating Engineering Society, 8*, 111-120.
50. Rowlands, E., Loe, D. L., McIntosh, R. M., & Mansfield, K. P. (1985). Lighting adequacy and quality in office interiors by consideration of subjective assessment and physical measurement. *CIE Journal, 4*, 23-37.
51. Loe, D. L., Mansfield, K. P., & Rowlands, E. (1994). Appearance of lit environment and its relevance in lighting design: Experimental study. *Lighting Research and Technology, 26*, 119-133.
52. Veitch, J. A., & Newsham, G. R. (1998). Lighting quality and energy-efficiency effects on task performance, mood, health, satisfaction and comfort. *Journal of the Illuminating Engineering Society 27*(1), 107-129.
53. Tiller, D. K., & Rea, M. S. (1992). Semantic differential scaling: Prospects for lighting research. *Lighting Research and Technology, 24*, 43-52.
54. Tiller, D. K., & Rea, M. S. (1990). Prospects for semantic differential scaling in lighting research. *Proceedings of the CIBSE National Lighting Conference, Cambridge, 1990* (pp. 110-127). London, UK: Chartered Institution of Building Services Engineers.
55. Perry, M. J., Campbell, F. W., & Rothwell, S. E. (1987). A physiological phenomenon and its implications for lighting design. *Lighting Research and Technology, 19*, 1-5.
56. Shepherd, A. J., Julian, W. G., & Purcell, A. T. (1989). Gloom as a psychophysical phenomenon. *Lighting Research and Technology, 21*, 89-97..
57. Shepherd, A. J., Julian, W. G., & Purcell, A. T. (1992). Measuring appearance: Parameters indicated from gloom studies. *Lighting Research and Technology, 24*, 203-214.
58. Tiller, D. K., & Veitch, J. A. (1995). Perceived room brightness: Pilot study on the effect of luminance distribution. *Lighting Research and Technology, 27*, 93-101.
59. Tiller, D. K. & Veitch, J. A. (1995). The effects of luminance distribution on perceived room brightness. *Proceedings of the 23rd Session of the Commission Internationale de l'Éclairage, New Delhi, India, November 1-8, 1995* (Vol. 1, pp. 144-147). Vienna, Austria: Bureau Centrale de la CIE.
60. Bean, A. R., & Bell, R. I. (1992). The CSP index: A practical measure of office lighting quality as perceived by the office worker. *Lighting Research and Technology, 24*, 215-225.
61. Baron, R. A. (1994). The physical environment of work settings: Effects on task performance, interpersonal relations, and job satisfaction. In B. M. Staw & L. L. Cummings (Eds.), *Research in Organizational Behavior* (Vol. 16, pp. 1-46). Greenwich, CN: JAI Press.
62. Baron, R. A. (1990). Environmentally induced positive affect: Its impact on self-efficacy, task performance, negotiation, and conflict. *Journal of Applied Social Psychology, 20*, 368-384.
63. Baron, R. A., & Thomley, J. (1994). A whiff of reality: Positive affect as a potential mediator of the effects of pleasant fragrances on task performance and helping. *Environment and Behavior, 26,* 766-784.
64. Baron, R. A., Rea, M. S., & Daniels, S. G. (1992). Effects of indoor lighting (illuminance and spectral distribution) on the performance of cognitive tasks and interpersonal behaviors: The potential mediating role of positive affect. *Motivation and Emotion, 16*, 1-33.
65. Heerwagen, J. H., & Heerwagen, D. R. (1986, April). Lighting and psychological comfort. *Lighting Design + Application, 16(*4), pp. 47-51.
66. Veitch, J. A., & Gifford, R. (1996). Assessing beliefs about lighting effects on health, performance, mood and social behavior. *Environment and Behavior, 28*, 446-470.
67. Begemann, S. H. A., Aarts, M. P. J., & Tenner, A. D. (1994, November). *Daylight, artificial light, and people*. Paper presented at the 1994 Annual Conference of the Illuminating Engineering Society of Australia and New Zealand, Melbourne, November 1994.

68. Aarts, M. (1994). *Towards a new kind of office lighting: Study for a human interactive lighting system*. Unpublished Master's thesis, Technical University of Eindhoven, the Netherlands.
69. Halonen, L., & Lehtovaara, J. (1995, November). Need of individual control to improve daylight utilization and user's satisfaction in integrated lighting systems. *Proceedings of the 23rd Session of the Commission Internationale de l'Éclairage, New Delhi, India, November 1-8, 1995* (Vol. 1, pp. 200-203). Vienna, Austria: Bureau Centrale de la CIE.
70. Leslie, R. P., & Hartleb, S. B. (1990, April). Human response and variability in the luminous environment. *Proceedings of the CIBSE National Lighting Conference, Cambridge, England, 8-11 April 1990* (pp. 87-99). London, UK: Chartered Institution of Building Services Engineers.
71. Boyce, P. R. (1973). Age, illuminance, visual performance and preference. *Lighting Research and Technology, 5*, 125-140
72. Saunders, J. E. (1969). The role of the level and diversity of horizontal illumination in an appraisal of a simple office task. *Lighting Research and Technology, 1*, 37-46.
73. Kaye, S. M. (1988). *Variations in the luminous and sonic environment: Proofreading and visual search effects; Mood states and frustration tolerance aftereffects*. (Project 84:SP:2). New York, NY: Lighting Research Institute.
74. Hughes, P. C., & McNelis, J. F. (1978). Lighting, productivity, and the work environment. *Lighting Design + Application, 8*(12), pp. 32-39.
75. Barnaby, J. F. (1980, February). Lighting for productivity gains. *Lighting Design + Application, 10*(2), pp. 20-28.
76. Berrutto, V., Avouac-Bastie, P., Fontoynont, M., & Belcher, C. (1994). An experimental assessment of the office workers' preferences regarding some energy saving artificial lighting strategies. In G. Guarracino (Ed.), *Proceedings of the European Conference on Energy Performance and Indoor Climate in Buildings, Lyon, France, Nov. 24-26* (pp. 834-840).
77. Kimmel, P. S., & Blasdel, H. G. (1973, January). Multidimensional scaling of luminous environment. *Journal of the Illuminating Engineering Society, 2*, 113-120.
78. Nelson, T. M., Hopkins, G. W., & Nilsson, T. H. (1983). *Steps toward convergence of optimal human and energy effectiveness: Interactions of indoor environmental factors and their effects on human performance, comfort, and mood*. Edmonton, AB: Department of Psychology, University of Alberta. (Report for the Alberta Environmental Research Trust, Edmonton).
79. Nelson, T. M., Nilsson, T. H., & Hopkins, G. W. (1987). Thermal comfort: Advantages and deviations. *ASHRAE Transactions, 93-1*, 1039-1054.
80. Nelson, T. M., Nilsson, T. H., & Johnson, M. (1984). Interaction of temperature, illuminance and apparent time on sedentary work fatigue. *Ergonomics, 27*, 89-101.
81. Horst, R. L., Silverman, E. B., Kershner, R. L., Mahaffey, D. L., & Parris, H. L. (1988, June). Research study on the effects of illumination on performance of control room tasks. *IEEE Fourth Conference on Human factors and Power Plants, Monterey, CA* (pp. 238-246). Piscataway, NJ: Institute of Electrical and Electronics Engineers.
82. Knez, I. (1995). Effects of indoor lighting on mood and cognition. *Journal of Environmental Psychology, 15,* 39-51.
83. 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.
84. Heerwagen, J. H. (1990). Affective functioning, "light hunger", and room brightness preferences. *Environment and Behavior, 22,* 608-635.
85. Begemann, S. H. A., Beld, G. J. van den, & Tenner, A. D. (1995). Daylight, artificial light, and people, Part 2. *Proceedings of the 23rd Session of the Commission Internationale de l'Éclairage, New Delhi, India, November 1-8, 1995* (Vol. 1, pp. 148-151). Vienna, Austria: Bureau Centrale de la CIE.
86. Butler, D. L., & Biner, P. M. (1987). Preferred lighting levels: Variability among settings, behaviors, and individuals. *Environment and Behavior, 19*, 695-721.
87. Shahnavaz, H. (1982). Lighting conditions and workplace dimensions of VDU-operators. *Ergonomics, 25*, 1165-1173.
88. 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.

89. Boyce, P. R. (1979). Users' attitudes to some types of local lighting. *Lighting Research and Technology, 11*, 158-164.
90. Slater, A. I., & Boyce, P. R. (1990). Illuminance uniformity on desks: Where is the limit? *Lighting Research and Technology, 22*, 165-17.
91. Bernecker, C. A., Davis, R. G., Webster, M. P., & Webster, J. P. (1993). Task lighting in the open office: A visual comfort perspective. *Journal of the Illuminating Engineering Society, 22*(1), 18-25.
92. Collins, B. L., Fisher, W. S., Gillette, G. L., & Marans, R. W. (1990). Second level post-occupancy evaluation analysis. *Journal of the Illuminating Engineering Society, 19*(2), 21-44.
93. Sanders, P. A., & Collins, B. L. (1996). Post-occupancy evaluation of the Forrestal Building. *Journal of the Illuminating Engineering Society, 25*(2), 89-103.
94. Ooyen, M. H. F. van, Weijgert, J. C. A. van de, & Begemann, S. H. A. (1987). Preferred luminances in offices. *Journal of the Illuminating Engineering Society, 16*(2), 152-156.
95. Ooyen, M. H. F. van, Weijgert, J. C. A. van de, & Begemann, S. H. A. (1986). Luminance distribution as a basis for office lighting design. *Proceedings of the CIBSE National Lighting Conference, Nottingham, England* (pp. 103-108). London, UK: Chartered Institution of Building Services Engineers.
96. Iwata, T., Hatao, A., Skukaya, M., & Kimura, K. (1994). Visual comfort in the daylit luminous environment: Structural model for evaluation. *Lighting Research and Technology, 26*, 91-97.
97. Miller, N., McKay, H., & Boyce, P. R. (1995, July). *An approach to a measurement of lighting quality*. Paper presented at the annual conference of the Illuminating Engineering Society of North America, New York, NY, July 29-31, 1995.
98. Veitch, J. A., Miller, N., McKay, H., & Jones, C. C. (1996, August). *Lighting system effects on judged lighting quality and facial appearance*. Paper presented at the 1996 Annual Conference of the Illuminating Engineering Society of North America, Cleveland, OH, August 5-7, 1996.
99. Bean, A. R., & Hopkins, A. G. (1980). Task and background lighting. *Lighting Research and Technology, 12*, 135-139.
100. Inui, M., Nakamura, Y., & Lee, J. S. (1989). Towards better office lighting. *Proceedings of the VI Lux Europa, Budapest, Hungary, October, 1989* (pp. 41-50). Budapest: Hungarian Society of Illuminating Engineering.
101. Tabuchi, Y., Matsushima, K., & Nakamura, H. (1995). Preferred illuminances on surrounding surfaces in relation to task illuminance in office room using task-ambient lighting. *Journal of Light and the Visual Environment, 19*, 28-39.
102. Yorks, P., & Ginthner, D. (1987, July). Wall lighting placement: Effect on behavior in the work environment. *Lighting Design + Application, 17*(7), pp. 30-37.
103. Loe, D. L., Rowlands, E., & Watson, N. F. (1982). Preferred lighting conditions for the display of oil and watercolour paintings. *Lighting Research and Technology, 14*, 173-192.
104. Aldworth, R. C., & Bridgers, D. J. (1971). Design for variety in lighting. *Lighting Research and Technology, 3*, 8-19.
105. Lloyd, C. J., Mizukami, M., & Boyce, P. R. (1996). A preliminary model of lighting-display interaction. *Journal of the Illuminating Engineering Society, 25*(2), 59-69.
106. Harvey, L. O., DiLaura, D. L., & Mistrick, R. G. (1984, October). Quantifying reactions of visual display operators to indirect lighting. *Journal of the Illuminating Engineering Society, 14*(1), 515-546.
107. Hedge, A., Sims, W. R., & Becker, F. D. (1995). Effects of lensed-indirect and parabolic lighting on the satisfaction, visual health, and productivity of office workers. *Ergonomics, 38*, 260-280.
108. Ellis, P., & Cave, C. (1982). Uplighting in the office: are low energy and user comfort compatible? *Energy conservation in the built environment: Proceedings of the CIBW67 Third International Symposium, Dublin, Ireland* (Vol. 4: Building services and controls, pp. 163-183). Rotterdam, the Netherlands: Commission Internationale des Bâtiments.
109. Ellis, P. (1986). Functional, aesthetic, and symbolic aspects of office lighting. In J. D. Wineman (Ed.), *Behavioral issues in office design* (pp. 225-249). New York: Van Nostrand Reinhold.
110. Katzev, R. (1992). The impact of energy-efficient office lighting strategies on employee satisfaction and productivity. *Environment and Behavior, 24*, 759-778.
111. Kiernan, V. (1994; December 10). Where there's light there's brass. *New Scientist, 144*(1955), p. 8

112. Bennett, C. A. (1986, August). Lighting, comfort, and performance in the workplace. *Lighting Design + Application, 16*(8), pp. 40-44.
113. Butler, D. L., & Biner, P. M. (1989). Effects of setting on window preferences and factors associated with those preferences. *Environment and Behavior, 21*, 17-31.
114. Collins, B. L. (1975). *Windows and people: A literature survey* (NBS Building Science Series 70). Washington, D.C.: U.S. Government Printing Office.
115. Wineman, J. D. (1987). Natural lighting in the workplace: The worker's perspective. In J. Harvey & D. Henning (Eds.), *Public environments. Proceedings of the 18th Annual Conference of the Environmental Design Research Association, Ottawa, May 29-June 2, 1987* (pp. 7-13). Washington, D.C.: EDRA.
116. Boubekri, M., & Haghighat, F. (1993). Windows and environmental satisfaction: A survey study of an office building. *Indoor Environment, 2*, 164-172.
117. Butler, D. L., & Steuerwald, B. L. (1991). Effects of view and room size on window size preferences made in models. *Environment and Behavior, 23*, 334-358.
118. Boyce, P. R. (1996). Illuminance selection based on visual performance - and other fairy stories. *Journal of the Illuminating Engineering Society, 25*(2), 41-49.
119. Boyce, P. R. (1987, May and June). Lighting research and lighting design: Bridging the gap. *Lighting Design and Application, 17*(5), pp. 10-12, 50-51; and, *17*(6), pp. 38-44.
120. Veitch, J. A., & Newsham, G. R. (1996, August). *Determinants of lighting quality II: Research and recommendations*. Paper presented at the 104th Annual Convention of the American Psychological Association, Toronto, Ontario, Canada. (ERIC Document Reproduction Service No. ED408543).

Table 1

Preferred Luminance Ratios and Luminances

Investigation	Luminance (cd/m^2)	Task:wall luminance ratio	Ceiling: wall luminance ratio	Wall maximum: minimum
Miller[3]	75			3:1
Loe et al.[51]	5		1:1	161:1
Berrutto et al.[76]				
Free choice	117-179			
Restricted power use	60-109			
Tregenza et al.[83]		2:1	1.6:1	
Ooyen et al.[94]		3.3:1		
VDT work (wall)	20-45			
Other tasks (wall)	30-60			
Miller et al.[97]				
Direct/indirect			1:3 through 3:1	
Parabolic direct			1:5 and 1:3	

Note. For Loe et al., the values are those of the configuration rated as most interesting, and the luminance is the average wall luminance in the field of view. For Berrutto et al., the luminances are mean values for walls on the right or the left of the desk in a room with VDTs.

Figure 1. Lighting quality: the integration of individual well-being, architecture, and economics.

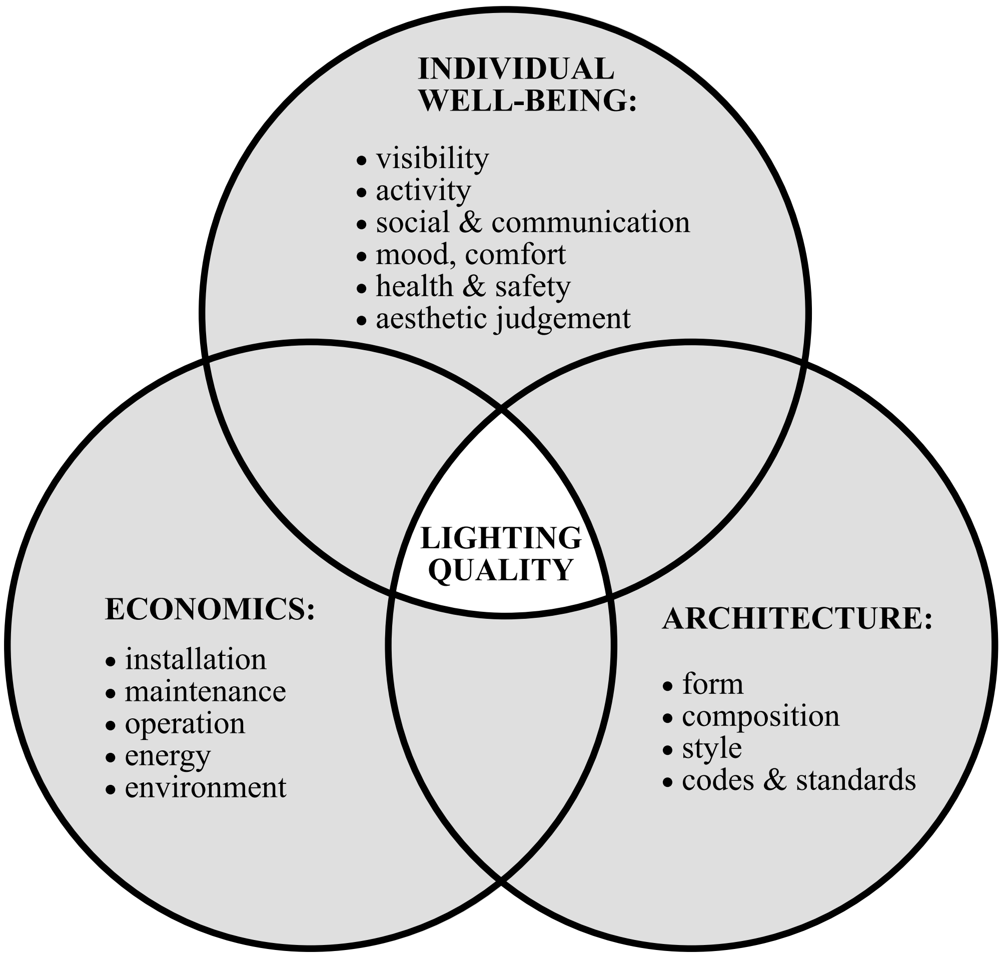

Figure 2. Conceptual model showing relationships between lighting conditions, individual processes, and individual outcomes.