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Linking Lighting Appraisals to Work Behaviors

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Abstract

Among those concerned with practical matters of office design, demonstrations that the work environment affects employees' well-being and work behaviors are thought to be important to support client decision-making. Veitch, Newsham, Boyce and Jones (2008) developed a conceptual model in which lighting appraisal and visual capabilities predicted aesthetic judgments, mood, and perfomance. This paper extends that model to include measures of work engagement, using experimental data originally reported by Newsham, Veitch, Arsenault and Duval (2003, 2004b). Structural equation modeling showed strong fit to a model in which lighting appraisals indirectly influenced work engagement through aesthetic judgments and mood. This evidence that providing a satisfactory work environment can contribute to employee effectiveness merits further study by environmental and organizational psychologists.

Introduction

Although not familiar to most psychologists, more than a century of lighting and applied vision science research has established clear relationships between the lit environment and visual performance (Boyce, 2003; Rea & Ouellette, 1991) and visual comfort (Commission Internationale de l'Eclairage (CIE), 1995; Committee on Recommendations for Quality and Quantity of Illumination (RQQ), 1966) that are reflected in present-day lighting recommendations (Commission Internationale de l'Eclairage (CIE), 2001; Illuminating Engineering Society of North America (IESNA), 2004). As a result, most offices in the industrialized world enjoy conditions that are adequate to see visual tasks and that do not cause extreme discomfort to their occupants. However, questions remain as to the possibility that lighting conditions might be further improved beyond this minimum level, to the point at which they could become positive contributors to employee performance and well-being (Boyce, 2004). Those concerned with providing office lighting and furnishings have long sought such evidence to support clients' design decisions.

Positive affect theory (Isen & Baron, 1991) suggests that working conditions do inflience employees' well-being and work behaviors. Positive affect induced by fragrance favorably influenced social behavior and task performance in two experiments (Baron, 1990; Baron & Thomley, 1994). Baron, Rea, and Daniels (1992) found modest evidence that variations in fluorescent lamp type and light level could induce positive affect and influence task performance and prosocial behavior. The latter study suggested that positive affect might be a mediating mechanism for lighting effects on work behaviors, but did not provide complete or clear guidance as to the lighting conditions that might be the most powerful triggers for positive affect.

Other investigations point to light distribution and the availability of individual (personal) control as desirable characteristics for office lighting. Lighting systems that use both direct and indirect lighting are preferred over direct-only systems (Boyce et al., 2006; Houser, Tiller, Bernecker, & Mistrick, 2002; Veitch & Newsham, 2000b). Surveys consistently report a preference for individual control over the work environment among office workers (Leaman & Bordass, 2001). Boyce, Veitch, Newsham, Jones, and Heerwagen (2006) found that individually-controllable lighting conditions were rated as more comfortable by a larger percentage of people than conventional fixed conditions. The availability of individual control appeared to confer resistance to fatigue, as individuals who had lighting control during the workday did not show declines in vigilance or persistence over the day, whereas those without control did (Boyce, et al., 2006).

The beneficial effects of individual environmental control might not be through commonly understood personal control mechanisms as they relate to stressful situations (Averill, 1973). In the case of control over the physical environment, positive affect might be the mechanism. Veitch and Newsham (2000a) reported no simple effects of control over lighting on task performance, mood, or satisfaction, but in a re-analysis of data from participants without control they found that those whose working conditions more closely approximated their personal preference showed improved mood and higher ratings of

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lighting satisfaction and overall environmental satisfaction (Newsham & Veitch, 2001). The data showed that for any given fixed light level (between 100 lx and 800 lx, the range possible in this experiment), at most 50% of the sample had a light level preference within 100 lx of that value, meaning that the only practical means to deliver one's preferred light level to individuals would be to provide individual control.

Veitch, Newsham, and Boyce (2008) re-analyzed the data reported by Boyce et al. (2006) to test a conceptual model built from a series of mediated linked regressions. The conceptual model had two paths, consisting of sequences of variables that had been measured in temporal sequence over the working day. The appraisal path was the most strongly supported, with explained variance on the order of 50% in three independent replications. This path led from the appraisal of lighting quality towards judgments of the attractiveness of the space. This in turn led to an improvement in pleasure, and pleasure in turn predicted end-of-day physical and visual comfort and environmental satisfaction. There also was a direct connection between the space attractiveness rating and the end-of-day measures. A second path, called the vision path, led from visual capabilities directly to typing task performance. Other hypothesized mediated links through competence or motivation towards task performance turned out to be not significant (Veitch, et al., 2008).

Newsham et al. (2003; 2004a) collected data concurrently with the data collection of the experiments by Boyce et al. (2006). There were many similarities in the questionnaires and tasks in the two projects, although different experimental designs. This paper reports a re-analysis of the Newsham et al. data, examining a conceptual model based on the one reported by Veitch et al. (2008).

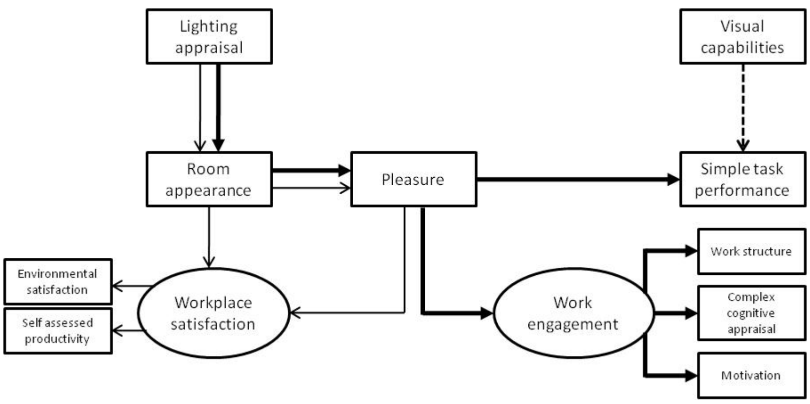

Figure 1. Hypothesized model. Thin lines represent the appraisal path, thick lines the perceptual path, and dotted the vision path.

The initial model (Model 1, Figure 1) tested here has an appraisal and a vision path, as in Veitch, et al. (2008) (although the exact composition is slightly different), and an affect path. The appraisal path leads from lighting conditions that either do or do not meet the individual's preferences; if they do, room appearance will be more favourably judged and this in turn will influence pleasure and workplace satisfaction. This path is the one reported by Veitch et al. (2008). The vision path is based on a century of lighting research; we predicted that visual capabilities would have a direct effect on simple task performance (Eklund, Boyce, & Simpson, 2000; Rea & Ouellette, 1991). The affect path represents our prediction, which we based on the positive affect model, that pleasure would positively predict both simple task performance and work engagement.

In addition to refinements of the model concerning performance measures, this analysis differs from the original Veitch et al. (2008) model in using structural equation modeling (SEM) instead of linked mediated regressions. The advantage of SEM over multiple regression analysis is the provision of both estimates of single pathways and indices of the fit of the entire model (Byrne, 2006; Kline, 1997).

Method

We give a summary of the methods used for the original data collection. Further details about the experimental space, setting, participants, procedure and variables can be found in Newsham et al. (2003, 2004a).

Setting and Lighting Conditions

The experiment took place in a dedicated office research laboratory in a government research institute in Ottawa, Canada. The experimental space was a windowless room 7 m x 4.9 m (20' x 16') and 2.75 m (9') high, with a standard suspended ceiling T-bar system. Within this space were two workstations of approximately 2.7 m x 2.9 m (8' 9" x 9' 6"), and a corridor area (Newsham, et al., 2004a).

The experiment was a mixed between-within subjects design. Participants experienced one of four different lighting designs (see Figure 2), set at one of four initial illuminance levels. Lighting design 1 represented a typical office lighting installation of ceiling-recessed parabolic fixtures, and served as a base case. Design 2 featured a "partition washer" fixture. Further, design 3 featured an angle-arm desk light, and design 4 was designed to resemble a new, low-energy lighting design through a workstation-specific dimmable direct/indirect fixture. The initial illuminance conditions of the first three designs were 200, 400, 600 and 800 lx. The fourth design deviated from these values because it was not able to generate that much light at the desktop, having instead four equally-spaced conditions of 150, 200, 250 and 300 lux (Newsham, et al., 2003). Lighting design and starting illuminance were between-subjects variables; individual control was a within-subjects variable, with all participants being given control for the last part of the day, after the midafternoon coffee break.

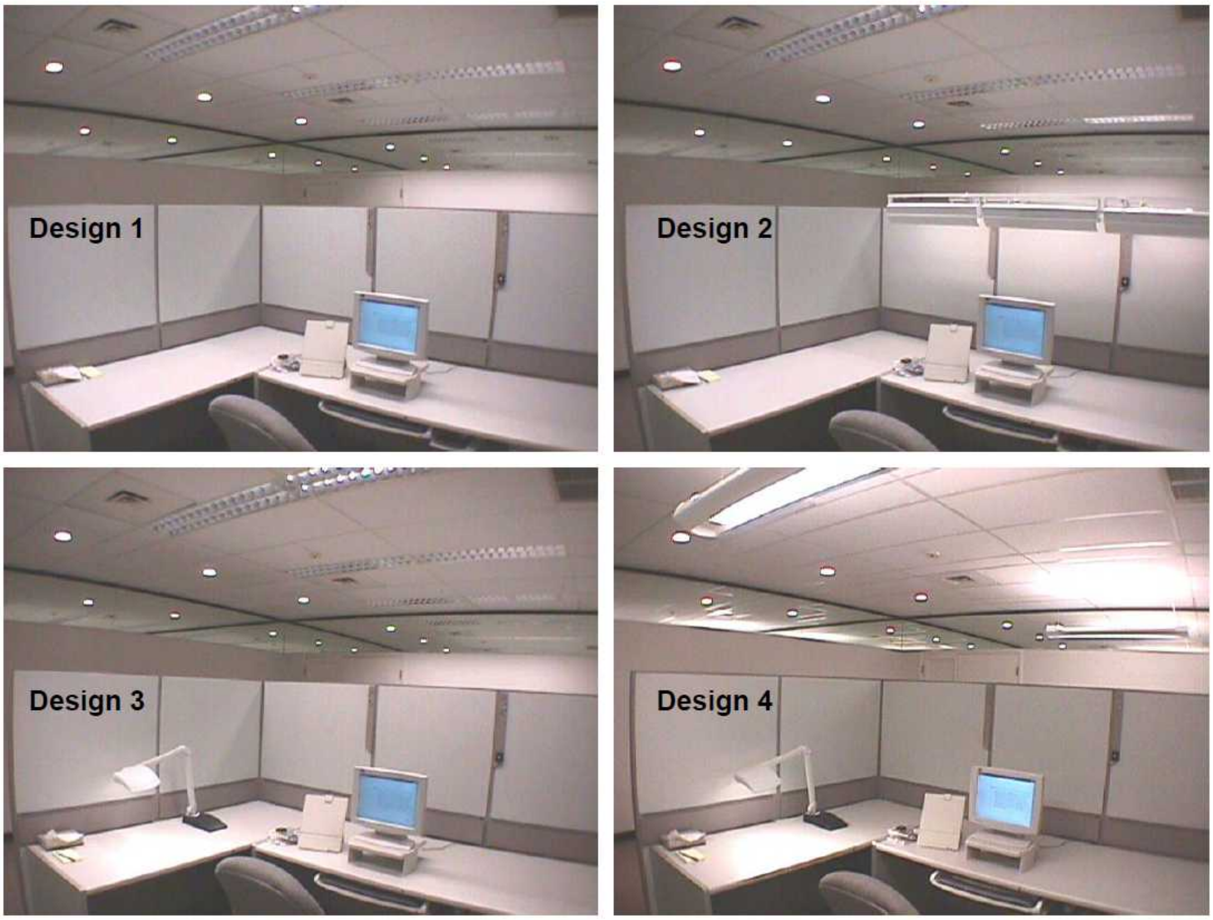

Figure 2. Photograph of experimental space showing the four lighting designs. Design 1 used recessed parabolic louvered 1 ft x 4 ft two-lamp luminaires in the ceiling. Design 2 used the same overhead luminaires as Design 1 and added a strip of 1-lamp "partition washer" luminaires to increase the luminance of the panel directly behind the computer monitor. Design 3 used the same overhead luminaires as Design 1 and added a compact fluorescent angle-arm task light on the side desk. Design 4 lit the cubicle with one workstation-specific direct-indirect suspended luminaire with three lamps, one providing indirect light by reflection from the ceiling and two lamps providing direct illumination to the work area; Design 4 also featured the same task light as Design 3.

Participants

All 118 participants were recruited from a local temporary-employment agency, and had a minimum age of 18 and maximum of 69, with an average of 28 years. Sixty of them were male, and 58 female. Recruitment and consent procedures were followed, and the participants were paid for their time at the standard rate for a clerical worker. The investigation was reviewed by the institute's Research Ethics Board.

Experimental Procedure

The day was divided into four parts, with the first being occupied by the consent procedure and training. After the training, participants repeated most tests and questionnaires three times. The first two parts were exactly the same, except for the first part being in the morning (between coffee break and lunch), and the second part during the early afternoon (immediately after lunch). During the third part of the day (after the afternoon coffee break), all participants were able to control the lighting, resulting in widely varying light levels in the last part of the day. The effect of control having been thoroughly examined by Newsham et al. (2004a), we here examined only data from the second period (immediately following lunch), being a time without control but after the participants had had time to experience and to assess the lighting.

Newsham et al. (2003) extensively described the procedure and measurements. Here, we describe only the aspects involved in the model test.

Lighting appraisal. We used the lighting quality scale developed by Veitch and Newsham (2000a). This is an average of four items measured on Likert scales, in which higher scores indicate that the lighting has been appraised as better.

Visual capabilities. These were measured using contrast sensitivity measured in correct responses per second. This was done by presenting a target grating (a small square area of horizontal or vertical stripes that varied in width and contrast as well as orientation) on the computer screen. The participant had to indicate, as fast as he could, whether he saw a target or not, by pressing a 'Yes' or 'No' key on the keyboard. Both accuracy and speed of detection were measured.

Room appearance. Participants assessed the attractiveness of the room on semantic differentials presented on the computer with a sliding scale scored from 0 to 100. For the present analysis we used attractiveness as described in Veitch, et al. (2008), which is the average of 9 items: attractive-unattractive; somber-cheerful; interesting-monotonous; colorful-colorless; subdued-stimulating; non-uniform-uniform; pleasant-unpleasant; beautiful-ugly; and like-dislike.

Simple performance. This was assessed by a typing task, measuring speed and accuracy. Participants had to retype 300 word passages from printed originals. The printed versions were given in three different print sizes: 8, 12 and 16. Software measured the speed and number of errors made per print size.

Pleasure. This measure of mood state is the average the scores of 6 semantic differential pairs on 9-point scales (Russell & Mehrabian, 1977).

Work engagement. Three measures indicated work engagement: complex cognitive appraisal, motivation, and work structure.

Complex cognitive appraisal was assessed using participants' ratings of their interest in reading an article based on a summary of it. Participants had to indicate their interest on the computer with a 0-100 slider.

Motivation was a behavioral measure, the willingness to persist at an impossible psychomotor task. This measure is analogous to the paper-based task developed by Feather (1962). The psychomotor task simulated a conveyor belt, across which symbols were travelling from the left to the right of the computer screen, through a box called the removal zone. Participants were instructed to remove target symbols as quickly as possible after they entered the removal zone, by pressing the spacebar. A spacebar press after a target entered the removal zone was recorded as a 'hit'. The speed that the symbols travelled gradually increased, until it was no longer possible to respond other than randomly. Participants' persistence was measured by the speed they gave up trying.

Work structure concerned participants' use of breaks between tasks. Changes in motivation were thought to be related to break durations, in this case between trials of the conveyor belt task and the typing task.

Workplace satisfaction. Two measures indicated overall workplace satisfaction: Environmental satisfaction, using the four-item scale developed by Sundstrom, Town, Rice, Osborn & Brill (1994), was one measure. The other measure was participants' opinions concerning the effects that the physical environment had on their self-assessed productivity (Wilson & Hedge, 1987).

Results

Results for the effects of lighting design were reported in (Newsham, et al., 2003) and control effects in (Newsham, et al., 2003, 2004b). The analysis reported here is collapsed across all lighting and illuminance conditions.

Descriptive Statistics

Before starting the analyses, we excluded five cases that were univariate outliers on one or more variable (standardized score > 3 or <-3) and two cases with missing data. No multivariate outliers were detected. Further, we tested all variables for normality with skewness values between -3 and +3 and kurtosis between -8 and +8 (Kline, 1997). All variables met these criteria. Table 1 shows the descriptive statistics of all variables used in the analyses and the scale on which they were measured. For composite scales, Cronbach's alpha values are given and the number of items on which they were based. Table 2 shows bivariate correlations for all variables, where asterisks mark significant correlations.

Table 1: *Descriptive Statistics*

Variable	*M*	*SD*	Skewness	Kurtosis	Cronbach's α	# items	Scale
Lighting appraisal	2.72	.81	-.77	.20	.88	4	0 - 4
Room appearance	37.95	13.73	-.06	.14	.89	9	0 - 100
Pleasure	4.36	1.27	.33	-.30	.88	6	0 - 8
Env. satisfaction	2.63	.80	-.73	.06	.85	4	0 - 4
Self assessed productivity	.59	1.84	-.42	-.34	-	1	-4 - +4
Visual capabilities	1.36	.39	-.43	-.18	-		
Simple task performance	2.76	.91	.43	.90	-		
Work structure	1.56	.39	.07	.29	-		
Complex cognitive appraisal	48.93	15.56	-.76	.29	-		
Motivation	6.31	1.68	.19	-1.02	-		

Note. N=111.

Table 2: *Bivariate Correlations*

Variable	1	2	3	4	5	6	7	8	9
1. Pleasure	-								
2. Lighting appraisal	.11	-							
3. Environmental Satisfaction	.21*	.50*	-						
4. Work structure	.03	.07	.06	-					
5. Self-assessed productivity	.19*	.45*	.59*	.06	-				
6. Visual capabilities	-.10	-.04	.00	-.11	.02	-			
7. Motivation	.23*	.06	.12	-.16	.21*	.21*	-		
8. Simple task performance	.01	-.04	.05	.01	.09	.41*	.19*	-	
9. Room appearance	.39*	.42*	.47*	.12	.48*	-.06	.08	-.07	-
10. Complex cognitive appraisal	.29*	-.09	-.02	.01	.20*	.12	.24*	.24*	.20*

Note. * $p<.05$.

Structural Equation Modeling

SEM is a collection of statistical techniques that can examine relationships between one or more independent variables and one or more dependent variables (Tabachnick & Fidell, 2001). Newsham et al. (Newsham, et al., 2003) had found few effects of lighting design on task performance or satisfaction in the second part of the day; therefore we did not include lighting design as a specific independent variable in the model.

We followed procedures outlined by Kline (1997), Byrne (2006), and Tabachnick and Fidell (2001), using EQS 6.1 for Windows (Bentler & Wu, 2003). We looked at the statistical significance of individual parameters and several indicators of goodness of fit for the model in general. These are: Chi-square; Chi-square/degrees of freedom; Goodness of Fit Index (GFI); Adjusted Goodness of Fit Index (AGFI); Comparative Fit Index (CFI); Bentler-Bonett Normed Fit Index (NFI); Bentler-Bonett Nonnormed Fit Index (NNFI); Standardized Root Mean Square Residual (SRMR) and Root Mean Square Error of Approximation (RMSEA). Further, the proportion of standardized residuals between -.1 and .1 were examined. In considering whether to modify the model, we considered the Lagrange Multiplier (LM) test results, always in the context of the theoretical basis of the proposed change. The LM test indicates whether model fit would be improved by estimating additional parameters (Tabachnick and Fidell, 2001).

Model 1

As explained above, Model 1 was partly derived from the linked mechanisms model of Veitch et al. (2008). After running this model in EQS, several parameter estimates were not significant, and also the general fit of the model was not significant. Table 3 summarizes the goodness of fit indicators of the models. Most of the indices for Model 1 do not indicate a good fit, as seen by comparing the test results to the column of target values, which are derived from established texts (Byrne, 2006; Kline, 1997; Tabachnick & Fidell, 2001). Increased pleasure did not lead to an improvement in workplace satisfaction and simple task performance. However, there was a significant path leading from lighting preferences to pleasure, and to workplace satisfaction through room appraisal. Also, the paths pleasure-work engagement and visual capabilities-simple task performance were significant.

Modified Models

We modified the model in response to these results. First, paths with insignificant parameter estimates (β-values) were deleted. These were: pleasure – workplace satisfaction; pleasure – simple task performance; and work structure as an indicator of work engagement. This led to Model 2, which is summarized in Table 3.

Table 3: *Fit Indices*

Goodness of fit	Target values	Model 1	Model 2	Model 3	Model 4
N		111	111	111	111
X^2		60.97	54.98	35.45	17.50
X^2/df	< 3	1.85	2.04	1.36	1.46
GFI	> .90	.90	.90	.93	.96
AGFI	> .90	.84	.84	.89	.90
CFI	> .90	.84	.85	.95	.97
NFI	> .90	.73	.75	.84	.90
NNFI	> .90	.79	.79	.93	.94
SRMR	< .10	.09	.10	.08	.06
RMSEA	< .10	.09	.10	.06	.07
% St. Res (-1 to +1)	> 90	76.37	76.77	82.22	89.28

Note. X^2 = chi-squared; X^2/df = chi-squared divided by degrees of freedom; GFI = goodness-of-fit index; AGFI = adjusted goodness-of-fit index; CFI = Comparative Fit Index; NFI = Bentler-Bonett Normed Fit Index; NNFI = Bentler-Bonett Nonnormed Fit Index; SRMR = Standardized Root Mean Square Residual; RMSEA = Root Mean Square Error of Approximation; % St. Res (-1 to +1) = percentage of standardized residuals between -1 and +1.

Model 2's results showed an improvement in fit, but did not meet most of the target test values. We next considered the results of the Lagrange Multiplier (LM) test for Model 2. For Model 2, the result suggested the addition of a direct path between lighting appraisal and workplace satisfaction; this was logical and also conceptually consistent with other research (Veitch, Charles, Farley, & Newsham, 2007). Other possible additions suggested by LM test for Model 2 had no theoretical justification, so we did not include them. Adding the extra path gave a better fit of the data than Model 2 (Model 3, shown in Table 3). For Model 3, only two indicators (AGFI and NFI) did not meet the criteria.

Although there is abundant evidence that visual capabilities should influence simple task performance (Boyce, 2003), the lack of connection between that path to other parts of the model was unsatisfactory; in this data set the lighting appraisal path appeared to be completely separate from the vision path. We ran a fourth variation without these two variables. Model 4, the final model, is pictured in Figure 3, and the standardized solution is shown in Table 4. As shown in Table 3, almost all fit indices improved for Model 4 in comparison with the other models. We consider its overall fit to be very good.

Table 4: *Standardized Solution and Explained Variance for Model 4*

Dependent variable				R^2
V2. Pleasure =	.39 * Room appearance	+ .92 * E2		0.15
V7. Environmental Satisfaction =	.78 * Workplace satisfaction	+ .62 * E7		0.61
V8. Self assessed productivity =	.75 * Workplace satisfaction	+ .66 * E8		0.57
V12. Motivation =	.44 * Work engagement	+ .90 * E12		0.19
V14. Room appearance =	.42* Lighting appraisal	+ .91 * E14		0.18
V16. Complex cognitive appraisal =	.55 * Work engagement	+ .83 * E16		0.31
F1. Workplace satisfaction =	.43 * Room appearance	+ .44 * Lighting appraisal	+ .68 * D1	0.54
F2. Work engagement =	.52 * Pleasure	+ .86 * D2		0.27

Note. V# = variable number to identify measured variables. E# = error associated with the respective variable number. F# = factor number to identify latent factors. D# = disturbance associated with the respective factor number.

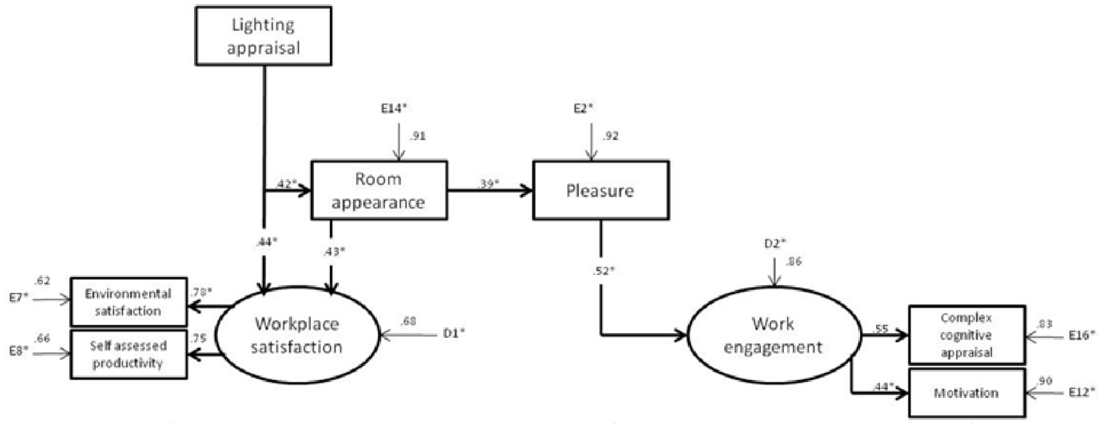

Figure 3. Model 4 (final), showing standardized regression weights for all paths. Paths with asterisks were free to vary. All paths were statistically significant (p<.05). E# = error associated with the respective variable number. D# = disturbance associated with the respective factor number.

Discussion

The most important conclusion from this investigation is that lighting appraisals predict workplace satisfaction and work engagement. People who appraise their lighting as good will also appraise the room as more attractive, be in a more pleasant mood, be more satisfied with the work environment, and more engaged in their work. Therefore, it is important to take into account what office workers think about their lighting, as this will lead to an interdependent chain of variables that influence work behaviors. The final model had excellent model fit and all paths were statistically significant. The environmental satisfaction variables were very well predicted, with explained variance comparable to that previously reported (Veitch, et al., 2008).

The final model, Model 4, had some important differences from the original model. Pleasure did not influence workplace satisfaction, as it had previously (Veitch, et al., 2008). In the present model, lighting appraisals had a direct effect on workplace satisfaction. Veitch et al. (2008) did not report having tested this direct effect, so we cannot say whether or not it might have existed in the earlier data. Other analyses of similar concepts have found that lighting satisfaction predicts overall environmental satisfaction (Veitch, et al., 2007).

Although in the present analysis, visual capabilities had the predicted effect on simple task performance (models 1-3), the best-fitting model (Model 4) did not include these variables. This is not a repudiation of well-known visual phenomena; rather it reflects the separation between the purely visual aspects of work performance and the role of affective responding to the work environment. As Boyce (2003) has written, lighting conditions can influence employees through vision and through motivation (or, as he says, “the message”). The absence of interconnections is explained by the fact that all the lighting conditions provided adequate levels of illumination to see the visual tasks, none had a direct glare source, and the simple task performed (typing) was a very well-learned one for these participants.

Veitch et al. (2008) reported an unexpected negative relationship between pleasure and motivation: People in a more pleasant mood were more likely to give up on the impossible task than to persist. The present study found, as had been predicted by positive affect theory, that pleasure positively predicted work engagement and, in turn, motivation. This is a stronger finding than the weak results reported by Veitch et al. (2008) in one of three samples.

Some of the differences in the models might be explained by differences between the two projects. The most important of these is the wider variation in lighting conditions to which participants responded (16 combinations of lighting design and illuminance here, versus 4 and 2 in the data sets analyzed by Veitch et al. (2008)). This could be expected to result in greater variability in the data and therefore less risk of restricted range (Kline, 1997). Moreover, the analysis technique used here permitted simultaneous tests of the paths and returned indices of overall fit, which was not provided by the earlier work. These are strengths of the present work.

Conversely, this investigation lacked one element that provided strength in the previous model: Veitch et al. (2008) had a temporal sequence to their data. That is, there was a logical sequence of time in the links between all variables. For example, for the appraisal path, appraisal was measured first early in the day, then preferences and mood, and eventually health and well-being at the end of the workday. Although the linked mediated regressions did not provide a causal test, the temporal sequence lends more causal weight to the original model than is possible here. All the variables in the present model were measured in the same time block. The model we present here establishes associations, not causal relationships.

The model does provide strong support for the idea than lighting appraisals affect mood, making workplace lighting a means to activate the positive affect mechanism. The importance of this to workplaces has several dimensions, from influence on social behavior (Baron, 1990; Baron & Thomley, 1994) to cognitive performance (Baron, 1990; Baron & Thomley, 1994; Miner & Glomb, 2010). We have reported a connection between lighting-induced positive affect and work engagement, suggesting that providing lighting conditions that are appraised as being good will promote desirable work behaviors.

In addition, lighting appraisals predicted workplace satisfaction both directly and through room appearance. The field counterpart to the workplace satisfaction measure used here has been called overall environmental satisfaction, and is a predictor of job satisfaction (Veitch, et al., 2007). Job satisfaction, in turn, is a predictor of organizational commitment and intent to turnover (Carlopio, 1996). Newsham, et al. (2009) examined an integrative model with various work related variables, linking (among others) lighting conditions to environmental satisfaction then job satisfaction and in turn employee well-being. Interestingly, they did not find a direct link of environmental satisfaction and job satisfaction, but it was mediated through satisfaction with management and employment – another example of the importance of the message delivered by the work environment. Harter, Schmidt, and Hayes (2002) demonstrated the organizational value of improved job satisfaction: improved customer satisfaction and business unit performance, and reduced turnover.

Lighting is of course but one element of the work environment, but it is an important one in that it serves several purposes: it illuminates all manner of tasks, it provides for safe movement through space, and it enables the aesthetic appreciation of the space. Lighting is also the largest single source of electricity consumption in North American offices, consuming 38% of all site electricity and 20% of all site energy when surveyed in 2003 (United States Energy Information Administration, 2009), making it a target for energy-efficiency strategies. Findings such as these underscore the importance of seeking to maintain or enhance lighting appraisals at a high level, or risk unintended organizational consequences of indiscriminate attempts to save energy at the expense of other lighting outcomes.

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