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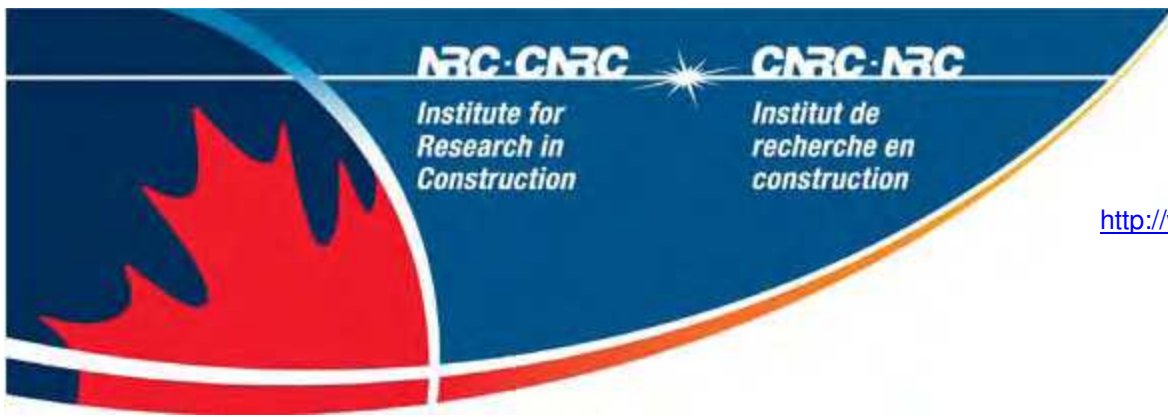
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HIGH-QUALITY LIGHTING: ENERGY-EFFICIENCY THAT ENHANCES EMPLOYEE WELL-BEING

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ABSTRACT

A century of lighting research has delivered a good understanding of how interior lighting affects visual processes, but less clarity concerning how to improve lighting quality beyond adequate seeing. This paper reports a field investigation into the behavioural effects of an energy-saving lighting retrofit. The results show that workstation-specific direct-indirect lighting with individual control is perceived as being more comfortable than recessed parabolic-louvered luminaires. Offices lit with the new lighting were more likely to be perceived as having better lighting than other similar offices. These effects have been previously associated with better outcomes related to organizational productivity. The pattern of results from several studies shows that good-quality lighting can deliver individual, organizational, and environmental benefits.

Keywords: luminaire, lighting appraisal, occupant satisfaction, energy-efficiency, organizational productivity

1. INTRODUCTION

One way to conceptualize lighting quality is to consider it as the result of the successful integration of three domains: the needs of the individual in the space; the architectural features of the space; and, the economic and environmental context of the project [1] (Figure 1). We have a good understanding of the effects of interior lighting on visual processes [2]. However, the means to improve the quality of the lit environment beyond merely adequate seeing — to provide lighting that enhances the health, wealth, and happiness of the occupant — remain unclear [2].

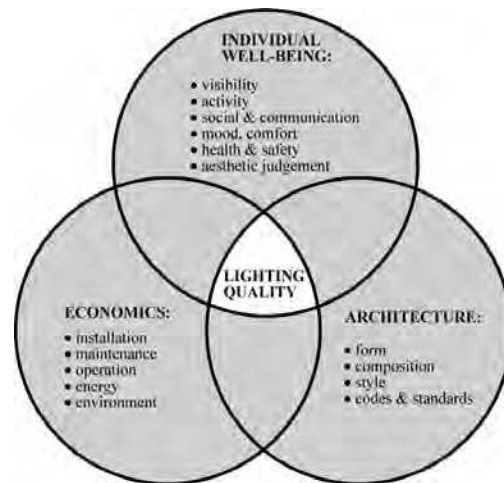


Figure 1. General model of lighting quality [1].

Recent laboratory research has begun to provide guidance on this question. Several investigations have demonstrated that short-term occupants of an office-like setting prefer the appearance of the space when it is lit with a combination of direct and indirect lighting [3-5]. Another variable showing consistent findings in sensitive laboratory experiments is individual control over workstation lighting. The benefits include more positive appraisals of the work environment and reduced lighting energy use [6-8]. Moreover, people who appraised their lighting as being of higher quality showed more favourable judgements of the appearance of the room, a more pleasant mood, and better well-being at the end of the working day [9].

Despite these desirable outcomes, one important question has remained: Do these laboratory results hold true in real organizations? The only way to address this question is to conduct a field study in a functioning organization. This paper reports on such a study. It builds on the laboratory experiments cited above [3] and on the linked mechanisms demonstrated in the laboratory data [9]. Figure 2 shows the linked mechanisms

map for the field study. Each concept in the linked mechanisms map has at least one associated measurement, either from the online surveys, on-site measurements, or archival data.

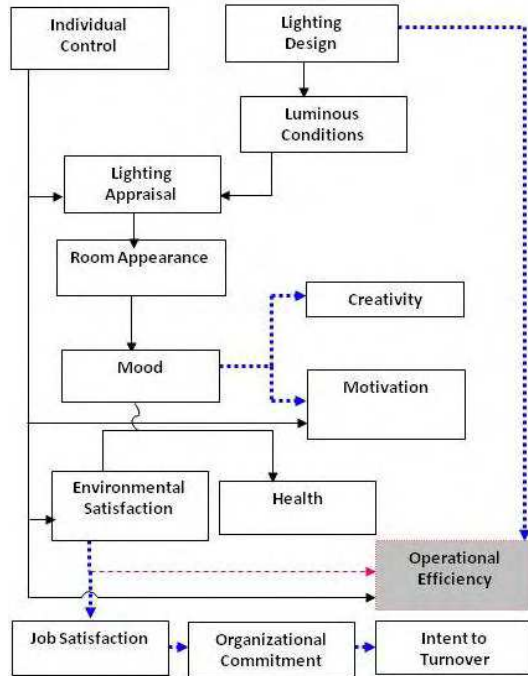


Figure 2. Proposed conceptual model. The solid black lines indicate relationships observed in the previous experiments. The blue dotted lines are relationships derived from other research. The red dotted line is a logical inference. The grey box denotes archival data. The white boxes are variables measured by the research team.

2. METHOD

2.1 Research Design

The investigation was a naturally-occurring field quasi-experiment taking place in three buildings that are occupied by one organization, a large Canadian corporation. The organization is undergoing a phased renovation of certain floors within its three buildings, involving changes to both lighting and furnishings. The old lighting consists of recessed parabolic-louvered luminaires (abbreviated PARAB) and the new lighting consists of workstation-specific individually-controllable suspended direct/indirect luminaires (abbreviated WSDI), or the same luminaire with the indirect lamp turned off (abbreviated WSD).

The investigation consisted of extensive surveys of occupants on three occasions and detailed physical measurements in offices.

The phasing-in of the lighting retrofit has provided comparison groups to permit the separation of effects associated with light distribution, individual control over lighting, and office furnishings. Table 1 shows the groups formed by the combinations of lighting and furnishings. In addition, some of the floors with WSDI and WSD lighting lacked individual control at either T_0 or T_1 , enabling comparisons of the effect of individual control between groups with the same luminaire and furnishings.

	PARAB	WSDI	WSD
Old panels – teal	Bldg 1, 2 474, 451, 373		
Old panels – grey	Bldg 3 4, 10, 12		Bldg 3 69, 80, 62
New panels	Bldg 1 20, 12, 8	Bldg 1, 2 61, 77, 43	Bldg 3 35, 50, 45

2.2 Participants

Over the three waves, a total of 3841 individuals were invited to participate at least once and 1750 people participated at least once, for an overall participation rate of 46%. (The number of survey invitations and respondents by wave were T_0 , 2749/1022, T_1 , 3035/1022, T_2 , 2856/791.) Data analysis focused on the 89% of participants whose offices were in the open-plan areas of the buildings, and for which the lighting and furnishings types could be confidently determined (T_0 , $N = 663$, T_1 , $N = 680$, T_2 , $N = 543$). Slightly more women responded than expected (49% of the sample was female, versus 45% of the organization) and the sample was slightly younger than the organization as a whole (sample weighted average age = 41 years; organization weighted average age = 42.8).

2.3 Building and Lighting Conditions

2.3.1 Buildings

The three buildings are located in one large metropolitan area in western Canada. Buildings 1 and 2 were constructed in the late 1980s/early 1990s; Building 3 was constructed in the mid-1990s and three floors were added in 2007. All the buildings have large windows on all sides. The old furniture and floor layout placed private

offices on the perimeter and cubicles centrally. One of the goals of the renovation was to increase daylight access for occupants; therefore the new layouts place private, enclosed offices in the interior and open-plan cubicles in the perimeter, and use lower panel heights to increase daylight penetration.

2.3.2 Furnishings

Both the old and new furnishings consist of modular systems furniture, but the old offices have higher panels covered in a dark fabric (average reflectance 27%, with accents of 45% grey and 10% maroon) and the new ones feature lower panels and lighter colours (predominantly white at 63% reflectance, with accents of 33% gold). A small subset of the offices have furniture more in the old style (grey panels, 35%) but have had the new lighting for several years. Figure 3 shows the old and new designs in views taken from the location of a seated occupant.



Figure 3 (top). Workstation with old lighting and furnishings. Figure 3 (bottom). Workstation with new lighting and furnishings.

2.3.3 Lighting

The PARAB lighting consists of recessed 2' x 4' (90%) and 2' x 2' (10%) recessed deep-cell (4") parabolic-louvered luminaires, each with 2 T8 lamps at 85 CRI and 3500 CCT and non-

dimming electronic ballasts. There is no individual control. As part of an extensive energy conservation program, some luminaires (principally those beside windows) have been delamped. Our photometric measurements were made in areas where there was no delamping.

The WSDI luminaires have three lamps, all 32WT8 lamps at 85 CRI and 3500 CCT. One of the three lamps provides the indirect component; it is run on a non-dimming electronic ballast at full power throughout the workday. The other two lamps provide the direct component, and are run on a dimming electronic ballast. The occupant can control the direct component using an interface on the computer in the workstation. Occupancy and daylight-linked dimming controls operate automatically on the direct lamps to reduce energy consumption. The indirect lamp remains at a fixed setting throughout occupied hours.

The WSD variation used in Building 3 uses the same luminaire and controls, but the indirect (up) lamp is always off. The luminaire design ensures that there remains a substantial indirect component to the distribution when the remaining lamps are on. The individual and automatic controls are the same as for the WSDI luminaires.

The research team visited the organization on three occasions and made extensive measurements of both luminance and illuminance at a large number of workstations both by day and night. Table 2 shows a selection of the average luminous conditions measured at night (i.e., electric lighting only) for PARAB, WSD, and WSDI luminaires.

	E_{DESK} (lx)	E_{EYE} (lx)	I_{FOV} (cd/m^2)	I_{LMM}
PARAB (N=132)	492 (142)	172 (80)	53 (20)	2.78 (1.36)
WSD (N=58)	425 (91)	185 (84)	50 (28)	2.21 (1.2)
WSDI (N=53)	557 (156)	281 (100)	70 (43)	2.04 (1.18)

2.4 Procedure

There were three measurement waves: a baseline (T_0) measurement (Spring 2008) and two post-renovation surveys, T_1 (Spring 2009)

and T₂ (Summer 2009). Each wave included an online survey for the building occupants. The surveys were composed of questionnaires and tasks to assess all of the concepts in the linked mechanisms map) together with demographic questions and questions about job demands and work group communications. The latter data were used to establish the comparability of the comparison groups, following the principles of quasi-experimental research design [10].

Each survey wave was announced to potential participants with an article in the weekly employee newsletter and a separate message to building occupants. Occupants of the target floors in the three buildings received an invitation to participate in an e-mail message from NRC-IRC. The invitation included a hyperlink to the survey, which was hosted on a secure server at NRC. Each survey wave was three weeks long, with reminder e-mails sent at the start of each week. As an incentive to participate, a contribution of \$5 per respondent was made to the organization's charitable foundation. Following each wave there was an announcement in the employee newsletter of the amount that had been generated.

The research team made a site visit in conjunction with each survey wave to assess the physical conditions at selected locations in the three buildings. At the T₀ site visit, the protocol included workstation acoustics, temperature, relative humidity, afternoon illuminance (with daylight), night (electric lighting only) illuminance and luminance. At T₁ and T₂, the protocol included temperature, relative humidity, afternoon illuminance and luminance (with daylight), night (electric lighting only) illuminance and luminance. We also obtained archival measurements of power consumption for the three buildings over the study period.

3. RESULTS

The survey included assessments of lighting quality, satisfaction with the physical environment, mood, room appearance, job satisfaction, organizational commitment, intent to turnover, and physical and visual comfort, as well as cognitive task performance and, at T₀ only, creativity. This report is limited to judgements of lighting quality using the Office Lighting Survey (OLS) [11] and satisfaction with windows and daylighting. Results for the other outcomes will be presented elsewhere.

We selected subsets of the data to conduct planned comparisons within and across measurement waves. The principal comparison in the investigation was between the PARAB and WSD/WSDI lighting installations. We also examined the additional benefits of obtaining individual control over lighting, and examined the effects of the furniture change alone.

3.1 Lighting Design Effects

3.1.1 With Old Furniture

We considered the two old furniture types to be roughly comparable in layout and reflectance, although clearly different in colour. There were two lighting types represented among the floors with old furniture: PARAB and WSD-C (WSD with control). All of the WSD workstations with old furniture included individual control over the lighting at all survey times. The results for this comparison were consistent over the three survey times. Overall, the participants judged their lighting to be more comfortable than the normative sample for the Office Lighting Survey; however, at all three times there was a significant difference between the two lighting types in which the proportion of people that judged WSD-C to be comfortable was greater than the proportion judging PARAB to be comfortable (Table 3).

Table 3. Per cent agreement at each survey time with the statement "Overall, the lighting is comfortable." (Norm: 69% agree), for PARAB and WSD lighting groups with old furniture. The first X² column tests the result for this group against the normative sample. The X² BG column is the test for the difference between two study groups * p < 0.05; ** p < 0.01; *** p < 0.001..

	Old Furn Group	N	%	X ²	p	X ² BG	p
T ₀	Parab	435	83	42.5	***	6.2	*
	WSD-C	64	95	20.7	***		
T ₁	Parab	415	84	41.5	***	6.4	*
	WSD-C	76	95	23.6	***		
T ₂	Parab	344	81	23.6	***	6.9	**
	WSD-C	59	95	18.5	***		

Similarly, there was a consistent result in which more WSD-C than PARAB respondents judged their lighting to be better than in similar workplaces in other buildings, at all three times (Table 4). The PARAB group itself was more likely than expected (based on the normative sample) to say that the lighting the same as in other workplaces, and less likely than expected to rate it as better.

Table 4. Responses to the question “How does the lighting compare to similar workplaces in other buildings?” for PARAB and WSD-C lighting groups with old furniture. Norm: 19% Worse / 60% Same / 22% Better. The first χ^2 column tests the result for this group against the normative sample. The χ^2 BG column is the test for the difference between two study groups. *** $p < 0.001$.

Old Furn. Group	N	W %	S %	B %	χ^2	p	χ^2 BG	p
T ₀ Parab	428	13	74	14	35.6	***	105.9	***
WSD-C	65	5	26	69	85.4	***		
T ₁ Parab	407	18	68	14	16.9	***	52.9	***
WSD-C	76	8	42	50	36.1	***		
T ₂ Parab	340	17	69	14	14.2	***	32.3	***
WSD-C	59	8	46	46	20.6	***		

3.1.2 With New Furniture

One floor had the new furniture, but PARAB lighting. There were sufficient respondents at T₀ (N=20) from this floor to compare their responses to a subset of individuals with new furniture and WSD lighting, but no individual control (WSD) (N=35). These results also showed the WSD lighting to be more likely to be rated as comfortable (100% agree for WSD, 65% agree for PARAB, $\chi^2_{(1)}=14.04$, $p < .001$) and as better than lighting in other similar workplaces (Table 5). Unfortunately, the response rates for the other survey times did not permit a repeat of this test for T₁ or T₂. In this contrast, note that the PARAB group ratings were not different from the normative sample.

Table 5. Responses to the question “How does the lighting compare to similar workplaces in other buildings?” for PARAB and WSD lighting groups with new furniture. Norm: 19% Worse / 60% Same / 22% Better. The first χ^2 column tests the result for this group against the normative sample. The χ^2 BG column is the test for the difference between two study groups. ** $p < 0.01$; *** $p < 0.001$.

New Furn. Group	N	W %	S %	B %	χ^2	p	χ^2 BG	p
T ₀ Parab	20	10	55	35	2.5		9.8	**
WSD	35	0	26	74	57.0	***		

3.2 Lighting Control Effects

We examined four comparisons to assess the effect of having individual control over lighting, two at T₀ and one at T₁

At T₀, there was a group with WSD and new furniture whose individual controls had not been activated. We compared this group to a group with WSD and control (WSD-C), but old furniture, and to a group with WSDI-C and new furniture. The OLS scores for all of these groups were better than the normative values, but they

did not differ. Individual controls were activated for the WSD group shortly after T₀.

At T₁, in an intervention, we arranged for individual controls not to be activated when occupants moved into a newly-renovated floor (WSDI). We compared their OLS scores to a WSDI-C floor in the same building, but which had been occupied for more than 18 months. Again, scores for both groups showed that the WSDI lighting was more comfortable and perceived as better than lighting in other workplaces, but the scores did not differ between the groups. Individual controls were activated shortly after T₁.

We also compared the OLS responses at T₁ (WSDI) and T₂ (WSDI-C) for people on the floor where we had intervened. The T₁ ratings were very high (86% of people rated the lighting as comfortable, and only 10% rated the lighting as worse than in other offices). The T₂ ratings were slightly higher, as expected (91% of people rated the lighting as comfortable, and none rated it as worse than in other offices). The differences between the times were not statistically significant, but this is attributable to the small sample size (at T₁, N=21, at T₂, N=11). On the comparison floor, which had WSDI-C at both times, there were also no statistically significant differences between T₁ and T₂; on that floor the trends showed either no change or a slight decline over time.

This investigation did not demonstrate an effect of individual control over lighting separate and in addition to the effect of having a workstation-specific luminaire. Two limitations might account for this. In each case in which we intervened to delay the addition of individual controls, people without control had moved to newly renovated spaces within the previous 3 months. This could have led to a ceiling effect because of the generally good appraisals of the luminaires. The small sample sizes for these comparisons are the second limitation to this study. Previous laboratory research has shown repeatable effects of individual control [3, 7].

3.3 Furnishings Effects

The renovation changed the visual environment dramatically because of both the new lighting and the new furnishings. We controlled as far as possible for the effects of the furnishings in the contrasts above. Nonetheless, we needed to examine differences in lighting evaluations in relation to changes in furnishings. This

comparison involved participants with WSD-C lighting at both T₁ and T₂. All of these participants worked in Building 3, so that insofar as possible, all conditions were constant between the two groups except for the furnishings. The results were consistent at T₁ and T₂. At both times, only one question showed a statistically significant difference: Participants with new furniture were more likely to judge the lighting as being better than in other similar workplaces (Table 6), although both groups were more likely than the normative sample to make that judgement. The new furniture has a positive effect, but the luminaire effect is in addition to this (note that the luminaire tests reported in section 3.1 held furniture constant).

Table 6. Responses to the question “How does the lighting compare to similar workplaces in other buildings?” for WSD lighting groups with old and new furniture. Norm: 19% Worse / 60% Same / 22% Better. The first X² column tests the result for this group against the normative sample. The X² BG column is the test for the difference between two study groups. * p < 0.05; ** p < 0.01; *** p < 0.001.

WSD-C Group	N	W %	S %	B %	X ²	p	X ² BG	p
T1 Old	80	9	41	50	37.6	***	6.9	*
T1 New	50	2	26	72	74.1	***		
T2 Old	63	8	48	44	20.1	***	12.1	**
T2 New	45	2	20	78	82.3	***		

The finding that furnishings influenced this lighting appraisal might explain the absence of a Control effect in the T₀ WSD contrast (section 3.2), when one group had control (with old furniture) and one did not (the group with new furniture). There was no difference on any OLS item at that time, perhaps because of the simultaneous opposing influences of control and new furniture.

3.4 Power Consumption

We had planned to examine archival data for measured power consumption for lighting in the three buildings over the study period. It was not possible to obtain all of the data required for this comparison. Moreover, the organization initiated a competitive energy conservation program shortly before T₀, which led to delamping efforts on floors without individual control and to actions such as the removal of the indirect lamps on the workstation-specific luminaires in Building 3. The strong goal of reducing power consumption, and ongoing communications on the topic, over the study period would have confounded the comparison had the data been available.

However, a previous study of lighting energy use comparing WSDI luminaires with varying

control strategies against PARAB luminaires with zonal on/off switching is pertinent here [12]. This study contrasted the same lighting strategies compared in our survey, and found that the WSDI installation together with occupancy, daylight-sensing, and individual controls reduced lighting energy use (and peak power demand) by 69% over the PARAB installation with the same furniture layout. A similar result would be expected in the renovated areas studied here.

4. DISCUSSION

The lighting industry has sought for decades to demonstrate that investments in good lighting will have financial benefits for organizations. This study is an important link in the evidentiary chain. As far as we are aware it is the largest field investigation of its kind.

The results presented here are limited to a single outcome measure, lighting appraisals using the Office Lighting Survey. They show that workstation-specific direct-indirect lighting with individual control is perceived as superior to recessed parabolic-louvered luminaires. Although many other outcomes remain to be analysed, this finding is significant because of its connection to previous investigations. Reporting on previous Light Right Consortium research, Veitch et al. [9] reported that people who judged the lighting to be more comfortable (using the same measure as reported here) also reported that the room was more attractive, that their mood was more pleasant, and that their end-of-day environmental and performance satisfaction was higher. An NRC-IRC study of open-plan offices found that higher overall environmental satisfaction predicted higher job satisfaction [13]. In turn, higher job satisfaction predicts higher organizational commitment and lower intent to turnover [14]. Further analyses of this data set will test this chain directly.

The lighting retrofit implemented here delivers known energy savings. It also delivers benefits for the office occupants. These benefits, based on sound organizational psychology research, translate into reduced personnel costs for organizations in the form of reduced turnover. Not all energy-efficiency retrofits will have these many beneficial outcomes. Those that pay attention to the many dimensions of lighting quality, will.

REFERENCES

1. Veitch, J.A., W. Julian, and A.I. Slater, *A framework for understanding and promoting lighting quality*, in *Proceedings of the First CIE Symposium on Lighting Quality*, J.A. Veitch, Editor. 1998, Commission Internationale de l'Eclairage: Vienna, Austria. p. 237-241.
2. Boyce, P.R., *Lighting research for interiors: the beginning of the end or the end of the beginning*. *Lighting Research and Technology*, 2004. 36: p. 283-294.
3. Boyce, P.R., et al., *Lighting quality and office work: Two field simulation experiments*. *Lighting Research and Technology*, 2006. 38(3): p. 191-223.
4. Houser, K.W., et al., *The subjective response to linear fluorescent direct/indirect lighting systems*. *Lighting Research and Technology*, 2002. 34(3): p. 243-264.
5. Veitch, J.A. and G.R. Newsham, *Preferred luminous conditions in open-plan offices: Research and practice recommendations*. *Lighting Research and Technology*, 2000. 32: p. 199-212.
6. Boyce, P.R., et al., *Occupant use of switching and dimming controls in offices*. *Lighting Research and Technology*, 2006. 38(4): p. 358-378.
7. Newsham, G.R., et al., *Effect of dimming control on office worker satisfaction and performance*, in *Proceedings of the IESNA Annual Conference, Tampa, FL, July 26-28, 2004*. 2004, IESNA: New York. p. 19-41.
8. Veitch, J.A. and G.R. Newsham, *Exercised control, lighting choices, and energy use: An office simulation experiment*. *Journal of Environmental Psychology*, 2000. 20: p. 219-237.
9. Veitch, J.A., et al., *Lighting appraisal, well-being, and performance in open-plan offices: A linked mechanisms approach*. *Lighting Research and Technology*, 2008. 40(2): p. 133-151.
10. Shadish, W.R., T.D. Cook, and D.T. Campbell, *Experimental and quasi-experimental designs for generalized causal inference*. 2002, Boston, MA: Houghton Mifflin.
11. Eklund, N.H. and P.R. Boyce, *The development of a reliable, valid, and simple office lighting survey*. *Journal of the Illuminating Engineering Society*, 1996. 25(2): p. 25-40.
12. Galasiu, A.D., et al., *Energy saving lighting control systems for open-plan offices: a field study*. *Leukos*, 2007. 4(1): p. 7-29.
13. Veitch, J.A., et al., *A model of satisfaction with open-plan office conditions: COPE field findings*. *Journal of Environmental Psychology*, 2007. 27(3): p. 177-189.
14. Carlopio, J.R., *Construct validity of a physical work environment satisfaction questionnaire*. *Journal of Occupational Health Psychology*, 1996. 1: p. 330-344.

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