Environmental satisfaction in open-plan environments: 5. Workstation and physical condition effects

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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20378817
Research Report (National Research Council of Canada. Institute for Research in Construction); no. IRC-RR-154, 2003-10-20

National Research Council Canada   Conseil national de recherches Canada

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Executive Summary

Open-plan offices are notorious for their unpopularity with occupants. Among the most common anecdotal complaints are problems with distraction and inadequate privacy. As part of the Cost-effective Open-Plan Environments project, a field study was conducted to examine the relationships between measured physical conditions and occupant satisfaction with those conditions.

A total of 779 workstations in nine buildings were visited. Lighting, acoustic, thermal and air movement conditions were recorded along with descriptive data about workstation size, partition height, and other characteristics. Occupants completed a 27-item questionnaire simultaneously with the measurements in their own workstations. The questionnaire covered satisfaction with individual features of the workstation, the environment overall, and the job, the rank ordered importance of seven physical features, and basic demographic characteristics. A mail-back questionnaire was provided to allow for longer comments about likes and dislikes.

This report concerns the effects of workstation physical conditions on five aspects of satisfaction: satisfaction with privacy and acoustics; satisfaction with lighting; satisfaction with ventilation; overall environmental satisfaction, and job satisfaction. Hierarchical multiple regression analyses controlled for age, job type, and gender first; then examined the effects of workstation characteristics and additional physical variables. Separate nonparametric analyses were conducted for the rank order data, and the text comments were transcribed and characterized.

Key findings are:

- **Environmental conditions in the offices generally met accepted standards.** This sample of workplaces was not random, but was not chosen to exemplify good or bad workplaces. Overall, there were relatively few instances of conditions that did not meet applicable guidelines or standards.
- **Having access to a window or to daylight strongly improves satisfaction with lighting**. Having a window, or daylight within 15 ft (5 m), strongly improves satisfaction with lighting. The desire for a window was a frequently mentioned comment among "things I would change" in the open-ended remarks.
- **Having a window in the workstation has a detrimental effect on satisfaction with ventilation and overall environmental satisfaction**. We believe this reflects the problems of heat gain and radiant cooling. Having a window is desirable, but poor thermal conditions are not.
- **Larger workstations are more satisfactory.** Increasing workstation size improves satisfaction with privacy.
- **Lower partition heights appear to improve satisfaction.** This finding is paradoxical, as it is contrary to previous research and common sense, particularly with respect to privacy. We suspect that it might reflect the desire for better daylight penetration, which lower partitions afford, and to the perception that lower partitions improve ventilation.
- **Concentrations of pollutants influence satisfaction with ventilation.** Even at concentrations within accepted limits, higher concentrations of carbon dioxide and other contaminants reduce satisfaction with ventilation.

The next steps for research in this area should include a wider range of variables relating to occupants, their work, and their organizations, to enable a finer-grained analysis and prescriptions for workplace design that are tailored to individuals and their specific requirements.

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1.0 Introduction

Open-plan offices have become the dominant interior design strategy for North American organizations, driven both by the opportunity for lower real-estate costs and by the appeal of the notion that reducing physical barriers between individuals might also remove social barriers (Brill, Margulis, Konar, & BOSTI, 1984; Sundstrom, 1987). However, persistent problems in open-plan offices have made them fodder for cartoonists such as Scott Adams (Dilbert™) and Francesco Marciuliano and Craig Macintosh ("Sally Forth"). Among the most common complaints are lack of privacy and distractions that prevent concentration (Brill, Weidemann, & BOSTI Associates, 2001; Brookes & Kaplan, 1972; Marans & Spreckelmeyer, 1982; Mercer, 1979; Sundstrom, 1982; Zalesny & Farace, 1987). Problems with other ambient conditions have also been reported, for instance poor indoor air quality and poor thermal comfort (Hedge, 1982; Woods, Drewry, & Morey, 1987).

Two factors have consistently emerged as important influences on environmental satisfaction: the area available to each employee and the degree of enclosure. Marans and Spreckelmeyer (1982) found that the amount of space available to the employee was the strongest predictor of satisfaction with the workstation, with larger sizes being more satisfactory. Other investigators have found that workstation size predicts assessments of privacy, with larger workstations being perceived as more private (Oldham, 1988; O'Neill & Carayon, 1993). Increasing enclosure is associated with higher ratings of privacy (Oldham, 1988; Sundstrom, Burt, & Kamp, 1980) and environmental satisfaction (e.g., Brennan, Chugh, & Kline, 2002; Brill et al., 1984; Marans & Yan, 1989; Oldham, 1988).

Anecdotal reports from interior designers and facilities managers indicate that cubicles in open-plan offices are smaller than ever, and often feature lower partitions than would have been typical in the 1980s ("Space planning", 2003). Concern that these changes would result in the creation of physical conditions that would reduce environmental satisfaction was among the reasons for the creation of the Cost-effective Open-Plan Environments project in 1999. It seemed likely that reducing cubicle size would increase noise and distraction along with occupancy, and that more cubicles might mean more barriers to light and air circulation. However, we could find few investigations that reported the physical conditions in sufficient detail to predict precisely how the physical conditions might relate to environmental satisfaction. Most of the investigations compared open-plan versus enclosed offices (e.g., Brennan et al., 2002; Mercer, 1979; Oldham & Brass, 1979; Spreckelmeyer, 1993) and in general lacked detailed measurements of physical conditions, or reported them in a manner that did not lend itself to open-plan design recommendations (e.g., Brennan et al., 2002; Marans & Spreckelmeyer, 1982; Oldham, Kulik, & Stepina, 1991; Oldham & Rotchford, 1983; Oldham & Fried, 1987; Sutton & Rafaeli, 1987). The few studies that did measure a wide range of physical conditions did not measure at individual workstations, but took averages across wide areas over periods of time (e.g., Hedge, Erickson, & Rubin, 1992). Moreover, relatively few investigations appear to have taken place since the late 1980s, which means that most predate the change to ubiquitous personal computing.

This field investigation was designed to fill a gap in the literature, by taking detailed measurements of both the physical conditions and the opinions of the occupants. Although a truly random sample of North American offices was not possible, the participants were from a variety of organizations, both public and private-sector, in several cities. Basic demographic variables were controlled, with the aim of providing information that could guide designers to providing open-plan office designs that will be satisfactory to the wide range of potential occupants. In addition to enlarging our understanding of how physical conditions influence environmental satisfaction, this cross-sectional field investigation is (to our knowledge) the only source of descriptive statistics on the physical conditions experienced in North American open-plan offices in the early 21st century.

2.0 Method

Detailed presentations of the method and participants in this cross-sectional field study have been presented elsewhere (Charles, Veitch, Farley, & Newsham, 2003; Veitch, Farley, & Newsham, 2002). A brief outline is provided here.

2.1 Participants

2.1.1 Buildings. Data were collected in nine buildings between spring 2000 and spring 2002. Five of the buildings were occupied by public sector Canadian organizations. Four were occupied by private sector organizations in either Canada or the United States. The buildings were located in Ottawa and Toronto (Ontario), Montreal and Quebec City (Quebec), and in the San Francisco Bay area (California). All buildings, and the specific locations within them, were selected because they contained open-plan offices occupied by white-collar workers, and because their management was willing to host the visit. A summary of the building characteristics at each site is shown in Table 1.

2.1.2 Occupants. A total of 779 occupants of the nine buildings participated in the investigation. They responded to a questionnaire about their satisfaction with the physical environment while the NRC team collected physical data pertaining to their workstations (see below). Demographic characteristics of these participants are shown in Table 2.

As may be seen in Table 2, several characteristics varied between buildings. One of the most striking differences occurred in the frequency with which respondents chose to respond to the questionnaire in English or French. We merged all the data, regardless of the language in which the questionnaire had been completed. The study had not been designed to provide data for a comparison between the two translations; moreover we were fairly confident that our translation and back-translation procedure had provided equivalent forms, given that the responses did not in general involve subtle emotional concepts that might differ from one language to another.

Table 1. *Summary of site characteristics.*

Building	Year Built	City	Sector	Visited	# Floors	Floor plate (sf)	Lighting	HVAC	Windows	Sound
1	1977	Ottawa	public	spring 2000	11 (4 visited)	39,000 (x 2 towers)	4' coffered prismatic fluorescent	ducted air VAV cooling / perimeter hot-water heating	non-operable	no sound masking
2	1975	Toronto	public	summer 2000	12 (3 visited)	40,000	4' recessed parabolic cube	ducted air VAV cooling / perimeter convention heating	non-operable	no sound masking
3	1975	Ottawa	public	spring 2000 & winter 2000	22 (4 visited)	18,000	4' recessed prismatic (some parabolic)	ducted air VAV cooling / perimeter hot and chilled water heating & cooling	non-operable	sound masking in use
4	1976	Ottawa	private	winter 2002	15 (1 visited)	16,000	2’ x 4’ prismatic	ducted air VAV cooling / perimeter hot-water heating	non-operable	no sound masking
5	1994	San Rafael	private	spring 2002	3 (3 visited)	40,000	2’ x 4’ recessed parabolic	ducted air VAV cooling / hot-water reheat	non-operable	sound masking in use
6	1984	San Rafael	private	spring 2002	5 (1 visited)	35,000	2’ x 4’ recessed parabolic	ducted air VAV cooling perimeter hot-water heating	non-operable	no sound masking
7	1916 (renovated 2000)	San Francisco	private	spring 2002	8 (1 visited)	41,000	8’ direct/ indirect	ducted air VAV	operable windows	sound masking in specific locations
8	1954	Montreal	public	spring 2002	4 (2 visited)	6,700	50% indirect / 50% 2’x 4’ parabolic	ducted air VAV / perimeter heating	non-operable	no sound masking
9	1989/90	Quebec City	public	spring 2002	3 (3 visited)	15,300	1’ x 4’ parabolic	Fan-coil with occupant-controlled ceiling vents, perimeter electric heating	non-operable	no sound masking

Table 2. *Demographic characteristics of participating occupants.*

Site	N	% English	% female /% male	Mean age (SD)
Full sample	779	79.5	47.6 / 51.5	36.2 (10.6)
Building 1	132	85.6	47.7 / 51.5	38.2 (12.7)
Building 2	160	98.8	48.8 / 50.6	37.8 (9.4)
Building 3	127	75.6	49.6 / 48.8	39.5 (10.1)
Building 4	52	94.2	23.1 / 75.0	32.1 (8.0)
Building 5	85	97.6	67.1 / 31.8	33.1 (9.6)
Building 6	48	100.0	62.5 / 37.5	29.8 (9.4)
Building 7	72	100.0	31.9 / 68.1	30.7 (7.3)
Building 8	47	0.0	53.2 / 44.7	38.8 (9.9)
Building 9	56	0.0	35.7 / 64.3	37.3 (10.1)

	Job Category (%)			
	Administration	Technical	Professional	Management
Full sample	27.1	24.9	38.4	8.6
Building 1	18.9	11.4	68.2	0.0
Building 2	47.5	11.3	32.5	8.1
Building 3	39.4	22.8	24.4	11.8
Building 4	1.9	57.7	30.8	7.7
Building 5	20.0	20.0	41.2	17.6
Building 6	33.3	14.6	35.4	16.7
Building 7	6.9	52.8	25.0	15.3
Building 8	31.9	34.0	29.8	2.1
Building 9	10.7	42.9	46.4	0.0

	Education (%)				
	High School	Community College	University courses	Undergraduate Degree	Graduate Degree
Full sample	11.6	15.1	14.6	34.0	22.7
Building 1	9.1	8.3	13.6	30.3	37.1
Building 2	13.1	21.3	16.9	26.3	20.0
Building 3	26.8	22.8	12.6	21.3	12.6
Building 4	0.0	5.8	13.5	36.5	42.3
Building 5	4.7	3.5	12.9	58.8	17.6
Building 6	6.3	8.3	18.8	41.7	25.0
Building 7	2.8	5.6	19.4	48.6	23.6
Building 8	12.8	27.7	14.9	25.5	17.0
Building 9	14.3	30.4	8.9	35.7	10.7

Note. Percentages that do not sum to 100 are the result of rounding error and missing data.

2.2 Independent Variables

During the data collection visit, the NRC team used a specially designed and constructed cart attached to a modified office chair to take measurements of the physical conditions at the workstation. These measurements included illuminance at various points on the work surface, sound level at the approximate location of a seated occupant's ear, temperature and air movement at head, knee, and ankle height of a seated occupant, relative humidity at torso height, and concentrations of carbon monoxide, carbon dioxide, total hydrocarbons and methane, as well as the size of the workstation, height of partitions surrounding the workstation, and number of enclosed sides of the workstation. Additional acoustic and illuminance measurements were taken at night, with no occupants and no daylight. This equipment was described in detail by Veitch et al. (2002).

2.3 Dependent Variables

Participating occupants completed a 27-item questionnaire. It consisted of 18 individual ratings of their satisfaction with specific environmental conditions, two overall ratings of environmental satisfaction, two items assessing job satisfaction, one set of rankings of the relative importance to that individual of 7 environmental features, and four demographic characteristics: age, sex, job type, and education level (Veitch et al., 2002).

Exploratory and confirmatory factor analyses were used to create three subscales of satisfaction from the 18 individual items (Charles et al., 2003; Veitch et al., 2002). Thus, the final set of dependent variables for this field study comprised Satisfaction with Privacy (Sat_Priv), Satisfaction with Lighting (Sat_Light), Satisfaction with Ventilation (Sat_Vent), Overall Environmental Satisfaction (OES), and Job Satisfaction (JobSatis). Each was calculated as the average of the contributing items, on scales from 1 to 7. The demographic characteristics were used as control variables in the regression analyses. Ranked importance was analysed separately and is reported below.

2.4 Procedure

Building occupants were contacted by memo or e-mail by their management prior to the visit by the NRC research team, to inform them about the investigation and to invite their participation. During the visit, a research team of two NRC staff visited individual workstations in the designated areas of the building. The team approached the occupants individually to invite their participation; over 95% agreed to participate. Having accepted the invitation, the participant was conducted to an adjacent workstation to complete the questionnaire on a handheld computer. At the same time, the NRC team replaced the participant's usual chair with the instrumented chair and took the physical measurements of the workstation. Each workstation visit took approximately 13 minutes. At the end of the visit the team moved on to the next occupied workstation. Two teams returned to the building to take night-time measurements of acoustic conditions and illuminances. Further details of the procedure are in Veitch et al. (2002).

Participants received no reward for participation, but both employees and management of the building received a report summarizing the physical conditions and aggregate satisfaction responses in that building.

3.0 Results and Discussion

3.1 Descriptive Statistics

3.1.1 Dependent variables: Satisfaction. As previously stated, the dependent variables were scale scores for five aspects of satisfaction, each measured on a scale from 1 to 7, with rising numbers reflecting greater satisfaction. The overall descriptive statistics are shown in Table 3. These statistics are for all cases with valid data (including cases excluded from regression analyses as univariate outliers). In general, among the aspects of the physical environment, Sat_Priv scores were lowest, and Sat_Light scores highest. JobSatis was very high, with a mean of 5.07 and median of 5.00. Over half of the sample were “satisfied” or “very satisfied” with their jobs.

Table 3. *Full sample descriptive statistics for dependent variables.*

Variable	N	Mean	SD	Median	Minimum	Maximum
SAT_PRIV	775	3.88	1.12	3.90	1.00	6.70
SAT_VENT	775	4.25	1.41	4.33	1.00	7.00
SAT_LIGHT	776	4.75	1.20	5.00	1.40	7.00
OES	745	4.05	1.31	4.00	1.00	7.00
JOBSATIS	767	5.07	1.08	5.00	1.00	7.00

3.1.2 Independent variables: Physical conditions. From the many physical measurements we selected a subset for the regression analyses. These were selected because of their relevance to the project (workstation size and partition height), their theoretical relevance (degree of enclosure), or to cover the most important elements of the acoustic, ventilation/temperature, and lighting conditions, as identified in previous COPE research or in the scientific literature. The descriptive statistics for each variable and their definitions are provided in tables 4, 5, 6, and 7. Sample sizes differ slightly from one variable to another because of equipment failures and operator errors; these were random losses. Acoustic variables have the greatest losses because in two buildings some workstations were not available for the necessary night-time measurements.

Table 4 shows the general workstation characteristics. The indicator for workstation size was the square root of the workstation area. Areas were calculated from the measured data for length and width, and corrected when the shape was known not to be square or rectangular (a few were triangular). We chose to convert to the square root for easier comparisons to other COPE project results, where square workstations were studied and results reported according to their length. For partition height, we took the height of the lowest side on which there was a partition on the basis that this was the most conservative estimate of enclosure that might affect privacy. We excluded open sides in this determination because all workstations were open on at least one side to provide an entrance, and because the degree of enclosure was separately captured. Figure 1 shows the histograms for workstation area and partition height, which were the principal variables of interest for the COPE project.

The median value of 8.70 ft for the square root of workstation area converts to approximately 76 square feet per workstation, which is within the range reported in a recent IFMA survey . In that survey, professional staff averaged 79 sf, senior clerical staff 77 sf, and general clerical staff 66 sf (our value here is across all job types).

Table 4. *Full sample descriptive statistics for workstation characteristics.*

Variable	Definition	unit	N	Mean	SD	Median	Minimum	Maximum
SQRTAREA	√workstation area (L*W)	ft	779	8.90	2.06	8.70	3.51	15.83
MINPH_NOOPEN	Minimum partition height, excluding open sides	in	779	60.84	9.82	64.00	30.00	109.00
			N			**# = 0**	**# = 1**	**# = 2**
PANELS_CAT	1 = not fully enclosed 2 = enclosed except for entrance		779			N/A	203	576
NO_DL_WI	0 = no daylight (more than 15 ft / 5 m from window) 1 = daylight available (within 15 ft / 5 m of window), but no window 2 = window in cubicle		779			330	131	318
WINDOW	0 = no window 1 = window in workstation		779			461	318	NA

Figure 1. *Histograms for workstation area (SQRTAREA) and partition height (MINPH_NOOPEN).*

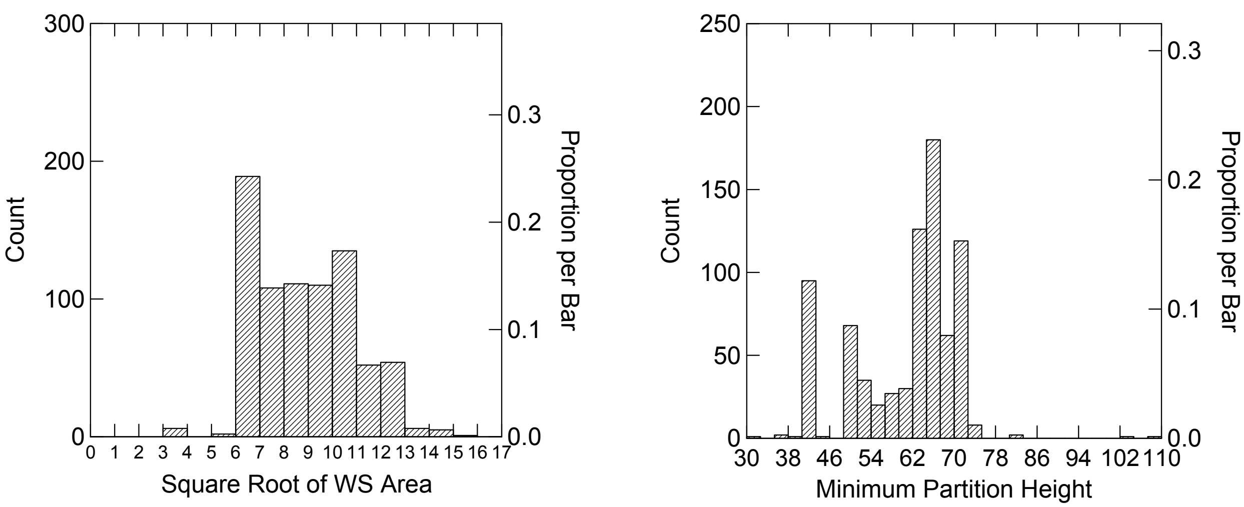

Table 5 shows the acoustic conditions. The acoustic variables used both daytime sound level measurements (excluding speech) and night-time measurements of sound propagation (cf. Veitch et al., 2002). For these analyses, we used the Speech Intelligibility Index calculation with the assumption of “normal” speech levels (American National Standards Institute, 1997). There is some evidence that actual speech in open-plan workstations is quieter than this (Warnock & Chu, 2002), in which case the true SII values would be lower. The values reported here may therefore be viewed as the worst-case scenario. The mean value for SII indicates that speech intelligibility is quite high; however, overall noise levels are in the range of desired conditions, as determined in a recent literature review (Navai & Veitch, 2003).

We also examined a new indicator of acoustic conditions, the difference between the low-frequency and high-frequency components of ambient noise. This characteristic was a good predictor of acoustic satisfaction in a COPE laboratory experiment (Veitch, Bradley, Legault, Norcross, & Svec, 2002) and we wished to examine its distribution and effects in the field.

Table 5. *Full sample descriptive statistics for acoustic conditions.*

Variable	Definition	unit	N	Mean	SD	Median	Minimum	Maximum
LNOISEA	A-weighted ambient sound level during working hours	dB(A)	734	46.43	3.77	46.66	36.24	59.87
SII	Speech Intelligibility Index (American National Standards Institute, 1997), calculated using 'normal speech', measured sound propagation, and daytime ambient sound level	Ratio, 0 - 1	734	0.51	0.15	0.51	0.00	0.91
LOHI_DBA	Difference between the A-weighted level of the low frequency sounds Low(A) (16 - 500 Hz) and the A-weighted level of the higher frequency sounds High(A) (1000 - 8000 Hz) (Veitch et al., 2002)	dB(A)	779	1.96	3.29	1.91	-12.54	13.29

Table 6 shows the lighting conditions observed in this sample. For the lighting conditions there was one subjectively scored variable, VDT_CAT. Three independent raters viewed photos of the VDT screen in each cubicle and judged the degree to which the photo showed reflected images of luminaires. The standards for "low", "medium", and "high" had been produced using computer simulations of lighting installations in open-plan offices in a separate COPE task (Newsham & Sander, 2003). Interrater agreement was not as good as hoped, with 3-way agreement on only 49% of cases , an average correlation between raters of r=.72, and kappa values between any two raters in the range 0.42 - 0.50. However, Cronbach's alpha (using each rater's score as an item, and each workstation as a subject) was very good, being equal to 0.88. Therefore, VDT_CAT scores were created by averaging the three ratings for each workstation and binning into three categories representing the low, middle, and highest thirds.

We selected three lighting characteristics for inclusion in the regression analyses. The average illuminance reaching the eye from all directions (called CUBEDAYT here) was selected as the illuminance value because it was the most consistent measurement, being affixed to the data-collection chair; desktop measurements proved to be less reliable because physical constraints or operator error led to variation in where the sensors were placed. There are no standards for desirable illuminance at the eye, but examination of the entire data set showed that the mean desktop illuminance was 362 lx (*SD* - 159) for workstations with no window, which is within recommendations for VDT offices (Illuminating Engineering Society of North America (IESNA), 1993). Depending on daylight and blind conditions, windowed workstations had desktop illuminances as high as 6700 lx. There are also no exact equivalents for our measure of desktop uniformity (UNIFDAYT) or directionality (EH2V). However, recommended practice is for fairly high desktop illuminance uniformity (Chartered Institution of Building Services Engineers (CIBSE), 1994; IESNA, 1993).

Table 6. *Full sample descriptive statistics for lighting conditions.*

Variable	Definition	unit	N	Mean	SD	Median	Minimum	Maximum
CUBEDAYT	Average illuminance on 6 faces of a cube in location of head of seated occupant	lux	779	261.81	251.93	202.60	9.20	3655.90
UNIFDAYT	(Maximum desktop illuminance over 4 locations - minimum desktop illuminance) / Maximum desktop illuminance	Ratio 0 - 1 (lower values more uniform)	779	0.44	0.20	0.41	0.01	1.00
EH2V	Ratio of illuminance on top of cube to average vertical on 4 sides	Ratio	779	2.34	0.92	2.25	0.37	12.16
			N			**# = 1**	**# = 2**	**# = 3**
VDT_CAT	Categorical rating of degree of luminaire reflections in VDT screen photo.		773			336	163	274

Table 7 shows the descriptive statistics for ventilation and thermal variables. Although we measured ventilation and thermal conditions at three heights, we used only the head-height measurements for further analyses. As expected, the measurements at the three heights were highly intercorrelated. It seemed likely that draught might be most problematic at the head because the majority of the offices used ceiling air diffusers, hence the choice of air velocity at that location. We chose the temperature measurement at that location to be consistent. Relative humidity was only measured at torso height. For indoor air quality we used carbon dioxide as an indicator of ventilation system activity, and created a new variable to indicate the total concentration of other pollutants. The new variable is the sum of standardized scores for three individual measurements; standardized scores were chosen because although each may be reported in parts per million, they differed widely in their expected distributions and in the levels at which each might be considered problematic. This new variable showed acceptable internal consistency reliability (Cronbach's alpha = 0.64). The values of air movement, relative humidity, temperature and carbon dioxide concentrations were all within recommended levels (American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE), 1992; ASHRAE, 2001).

Table 7. *Full sample descriptive statistics for ventilation conditions.*

Variable	Definition	unit	N	Mean	SD	Median	Minimum	Maximum
AIR_V_H	Air velocity at head height of seated occupant (an indicator of draught)	m/s	779	0.10	0.05	0.08	0.01	0.43
RTD_H	Air temperature at head height of seated occupant	°C	779	23.27	0.95	23.27	20.39	28.71
REL_HUMID	Relative humidity, measured at torso of seated occupant	%	779	29.91	10.78	28.70	13.05	58.82
FDCO2	Carbon dioxide concentration	ppm	779	648.37	97.28	639.79	469.51	1103.90
POLLUT	Summed standardized score of 3 pollutants: carbon monoxide, total hydrocarbons, and methane		779	0.00	1.78	-0.11	-4.70	8.05
			N			**# = 0**	**# = 1**	
DL_OUT	Air diffuser location 0 = in workstation 1 = outside workstation		777			590	187	

3.1.3 Intercorrelations. Table 8 contains intercorrelations between all the independent variables, using pairwise deletion of missing data. With one exception, there is no evidence of multicollinearity. The exception is the correlation of .61 between SQRTAREA and MINPH_NOOPEN, which approaches the level at which statistical problems may arise (Tabachnick & Fidell, 2001). The correlation indicates that larger workstations tend to have higher partitions. Although it might be considered an artifact of the way in which we selected buildings; we sought buildings with smaller workstations and shorter partitions to expand the original 3-building data set reported by Charles and Veitch (2002), it could also reflect a real condition in workplaces. Indeed, concerns expressed to us by design professionals about the shift to smaller workstations and lower partitions was an initial impetus behind the development of the COPE project. It seems likely that the incidence of small workstations with tall partitions is relatively rare in open-plan offices generally.

Table 8. *Intercorrelations between independent variables*

	AGE_COMBINED	GENDER	ADMIN	MGR	PROF	SQRTAREA	MINPH_NOOPEN	PANELS_CAT	NO_DL_WI	WINDOW	LNOISEA	SII	LOHI_DBA	CUBEDAYT	UNIFDAYT	EH2V	VDT_CAT	AIR_V_H	RTD_H	REL_HUMID	FDCO2	POLLUT	DL_OUT
AGE_COMBINED	1.00																						
GENDER	0.04	1.00																					
ADMIN	0.04	-0.37	1.00																				
MGR	0.03	0.10	-0.19	1.00																			
PROF	0.09	0.07	-0.49	-0.25	1.00																		
SQRTAREA	0.27	-0.01	0.13	-0.01	0.14	1.00																	
MINPH_NOOPEN	0.08	-0.01	0.06	-0.07	0.13	0.61	1.00																
PANELS_CAT	0.20	-0.07	0.11	-0.04	0.13	0.49	0.36	1.00															
NO_DL_WI	0.18	0.02	0.02	0.10	0.01	0.31	0.06	0.08	1.00														
WINDOW	0.20	0.03	0.04	0.08	0.03	0.41	0.15	0.11	0.92	1.00													
LNOISEA	-0.15	0.00	0.02	0.14	-0.20	-0.36	-0.35	-0.21	0.07	0.03	1.00												
SII	0.04	0.05	-0.09	-0.04	0.09	-0.06	-0.11	-0.29	0.00	0.01	-0.58	1.00											
LOHI_DBA	0.06	-0.01	-0.06	-0.06	0.19	0.24	0.14	0.20	-0.11	-0.08	-0.38	0.38	1.00										
CUBEDAYT	0.09	0.04	0.03	0.02	0.06	0.14	-0.06	0.03	0.37	0.37	0.01	0.06	0.01	1.00									
UNIFDAYT	0.06	-0.06	0.13	-0.01	-0.06	0.02	0.02	0.06	0.08	0.11	0.05	-0.03	-0.04	0.06	1.00								
EH2V	-0.07	0.05	-0.03	-0.11	0.04	0.03	0.21	0.08	-0.37	-0.34	-0.12	-0.03	-0.01	-0.13	-0.28	1.00							
VDT_CAT	0.02	0.01	0.00	0.00	0.00	0.09	0.06	0.04	0.00	-0.01	-0.01	-0.04	-0.08	-0.04	-0.14	0.00	1.00						
AIR_V_H	-0.08	0.14	0.00	0.04	-0.11	-0.16	-0.23	-0.08	-0.01	-0.03	0.17	-0.03	-0.07	0.06	0.07	-0.10	0.00	1.00					
RTD_H	-0.10	0.12	-0.14	-0.06	0.01	-0.33	-0.30	-0.23	-0.15	-0.18	0.12	0.13	-0.03	0.11	-0.09	0.01	-0.07	0.15	1.00				
REL_HUMID	0.06	-0.01	0.15	0.01	-0.13	-0.19	-0.34	-0.03	-0.01	-0.02	0.06	0.11	-0.03	0.00	0.19	-0.13	-0.06	0.20	-0.06	1.00			
FDCO2	0.04	0.06	-0.04	-0.08	0.07	-0.05	0.08	-0.01	-0.05	-0.06	-0.17	0.11	-0.13	-0.06	-0.02	0.07	0.02	-0.04	0.13	0.03	1.00		
POLLUT	0.09	-0.03	0.14	-0.08	0.00	0.10	-0.01	0.11	-0.08	-0.03	-0.17	0.13	0.13	-0.01	0.13	-0.03	-0.07	0.02	-0.09	0.58	0.09	1.00	
DL_OUT	-0.09	-0.03	-0.07	0.11	-0.06	-0.41	-0.34	-0.18	-0.15	-0.19	0.21	0.05	-0.12	-0.05	-0.03	-0.10	-0.06	0.04	0.25	0.11	0.00	0.09	1.00

Another area of high intercorrelation is between LNOISEA and SII. This is not surprising; LNOISEA is an input to SII. Louder ambient noise can mask speech sounds.

The bivariate correlations between the independent variables and the dependent variables are shown in Table 9, also using pairwise deletion of missing data. These are low, which suggests that effect sizes are likely to be small. Intercorrelations between the dependent variables are not shown, as they are reported and analyzed in more detail elsewhere (Charles et al., 2003).

Table 9. *Correlations of independent variables (rows) with dependent variables (columns)*

	SAT_PRIV	SAT_LIGHT	SAT_VENT	OES	JOBSATIS
AGE_COMBINED	-0.09	0.03	-0.05	-0.04	-0.09
GENDER	0.03	0.03	0.21	0.02	0.00
ADMIN	0.07	0.05	-0.13	0.09	-0.06
MGR	-0.02	0.03	0.03	-0.03	0.02
PROF	-0.03	-0.03	0.04	-0.10	-0.01
SQRTAREA	0.12	0.07	-0.17	-0.01	-0.12
MINPH_NOOPEN	0.08	-0.05	-0.20	-0.09	-0.14
PANELS_CAT	0.03	-0.01	-0.13	-0.04	-0.12
NO_DL_WI	0.01	0.28	-0.08	0.04	0.03
WINDOW	-0.01	0.26	-0.12	-0.01	0.00
LNOISEA	0.00	-0.05	0.06	0.03	0.14
SII	-0.08	0.05	0.03	0.01	-0.03
LOHI_DBA	-0.03	-0.03	0.02	0.02	-0.04
CUBEDAYT	0.01	0.08	-0.02	0.06	0.00
UNIFDAYT	-0.05	-0.07	-0.03	-0.02	0.01
EH2V	0.06	-0.10	-0.02	-0.03	-0.04
VDT_CAT	0.04	-0.08	0.00	-0.01	-0.03
AIR_V_H	0.01	0.00	-0.03	0.00	0.03
RTD_H	-0.06	-0.10	-0.05	-0.05	0.07
REL_HUMID	0.02	0.12	0.10	0.09	0.00
FDCO2	-0.07	-0.06	-0.12	-0.06	-0.12
POLLUT	0.01	0.03	-0.02	0.03	-0.11
DL_OUT	-0.14	-0.12	0.02	-0.09	0.00

3.2 Analytic Strategy

This investigation was a cross-sectional field survey. We sought in the analyses reported here to relate the measured physical conditions with the satisfaction of the occupants with those conditions. A separate report describes analyses involving only the physical conditions (Newsham et al., 2003a), and another reports a general model of the relationships between the questionnaire variables alone (Charles et al., 2003).

The general approach taken is hierarchical linear regression and follows generally accepted practices within the behavioural sciences, as described in standard works such as those by Kerlinger and Lee (2000), Pedhazur (1997), and Tabachnick and Fidell (2001). This section describes the criteria applied to all analyses reported here.

3.2.1 Data cleaning. We examined all of the data carefully for inconsistencies and errors in data entry, and corrected these where possible, leaving data as missing if there were any question.

For the dependent variables there was very little missing data, and no evidence of any systematic missing data. We calculated scale scores as the average of available data on the contributing items, but required valid data on more than 50% of the contributing items for the scale score to be valid. Otherwise, the scale score was set to missing. This criterion resulted in four missing cases for Sat_Priv, four for Sat_Vent, three for Sat_Light, 34 for OES, and 12 for JobSatis.

We tested each dependent and independent variable for normality. Following recommendations by Kline (1997), we looked for skewness values between +3 and -3, and kurtosis values between +8 and -8. All the variables met these criteria.

We further examined the data for univariate and multivariate outliers. Univariate outliers were defined as cases on which the absolute value of the standardized score for that variable was greater than 3. These cases were omitted from analysis.

Multivariate outliers were examined for each analysis. We first ran the analysis with all cases except for the univariate outliers. We then examined the Mahalanobis distance statistic for each case. Very large values of this statistic indicate that the case is an extreme outlier and probably is having an undue effect on the outcome. Cases for which the Mahalanobis distance exceeded the critical value for that analysis were identified as multivariate outliers and excluded from analysis. (Mahalanobis distance is distributed as a chi-square and is tested against the degrees of freedom, which is the number of predictor variables in the model. We tested against a very conservative alpha of $p<=.001$.) For most analyses there were no multivariate outliers, and there were never more than two. We did not look for further multivariate outliers after the first exclusion.

The results presented below are for the final sample, excluding both univariate and multivariate outliers. Because outliers were determined separately for each analysis, sample sizes vary somewhat from one analysis to another. We chose this approach to preserve as large a sample size as possible for each analysis.

3.2.2 Independence of observations.. The buildings were not randomly sampled; rather they were selected based on the willingness of management to provide access and on the availability of a suitable number of open-plan workstations. Later buildings were selected deliberately to ensure a broader range of workstation sizes in the overall sample. Moreover, although workstation size tends to vary within a building it is often the case that organizations use a limited range of workstation sizes and partition heights, so that the range within any one building is limited. The sample therefore has the possibility of being biased by the selection of certain organizations or certain buildings and by the confound of buildings and workstation characteristics. This means that observations from all the people in one building might be highly correlated by virtue of coming from one organization or because of commonly experienced conditions. If so, this would violate a fundamental statistical assumption, that observations are independent of one another.

Although the remedies for these problems are few, we did conduct a series of statistical analyses to determine the legitimacy of combing individual data from the buildings into one large sample in which we ignored the building as a variable. These tests followed the guidance of Dansereau, Alutto, and Yammarino (1984)and Yammarino and Markham (1992) regarding independence of observations.

Four statistical criteria were used to examine the agreement among occupants in a building regarding the five satisfaction measurements. Traditional one-way ANOVAs were conducted in which building served as the independent variable and the five satisfaction scales served as the dependent variables. Then, using the information produced in the ANOVA (i.e., sums-of-squares and mean square), other relevant statistics were calculated (Table 10). All cases were used in these analyses, although there were 7 cases with missing data on JobSatis, 6 missing on OES, and three each on Sat_Priv, Sat-Light, and Sat_Vent.

The Intraclass Correlation Coefficient 1, or ICC(1), assesses whether occupants in the same building reliably agreed in their responses. The ICC(1) has values that range from .00 to .50, with a median of .12 (James, 1982). An ICC(1) value of .12 or greater indicates reliable agreement. By this criterion, all of the satisfaction scales showed within-building agreement, as all had ICC(1) values >= .12.

The ICC(2) measures how reliably buildings can be differentiated based on satisfaction scores (Bartko, 1976). The closer ICC(2) is to 1.00, the better the measurement indicates whether the buildings can be reliably differentiated in terms of individual responses on the five satisfaction scales. The criterion of .85 or higher was used as an indicator of between-building differences, following Griffith (1997). Only one of the five scales passed this criterion, with Sat_Vent having ICC(2) = .861.

The E-tests (a ratio of the between-eta and within-eta) of practical significance provides an index of the magnitude of the effects (within- and between-group analysis - WABA) (Yammarino & Markham, 1992). The test of significance for the E-Test is not dependent on degrees of freedom but is geometrically based. Briefly, a 90^0 angle representing the relationship between two sets of scores indicates that the scores are orthogonal. The smaller the angle becomes, the stronger the observed relationship. In WABA, angles are considered for between versus within etas. The difference between the pair of angles in each case is what is tested. Thus, the larger the angular difference, the more likely that the etas are significantly different. We used the critical value for the most conservative, 30^0 test, E <= 0.58 (Dansereau et al., 1984). On this test all five satisfaction scales showed practical significance, meaning that the within-groups variance is greater than the between-groups variance. This is an indicator that observations are independent of building.

Two *F* tests examine the statistical significance of the between-groups versus within-groups variance. The traditional *F* test compares between-group variance/within-group variance, to determine whether there are meaningful differences between buildings on the variable of interest. All five traditional *F* tests are statistically significant, indicating that there are between-buildings differences in all of the satisfaction scales. However, in cases in which the within-groups eta is the larger of the two, as in the present results (as shown by the E tests), a corrected F test is the appropriate indicator of the significance of the within-groups effect (Dansereau et al., 1984). The test is the inverse of the traditional F test. For the present results, three of the corrected F tests are statistically significant, suggesting that there are differences between buildings in the amount of within-groups variability on these three variables (OES, Sat_Priv, and Sat_Light).

Table 10. *Summary of independence analyses.*

Variable	ICC(1)	ICC(2)	eta_{bn}	eta^2_{bn}	eta_{wn}	eta^2_{wn}	E Test**	Traditional *F* Test	Corrected *F* Test
SAT_PRIV	0.270†	0.769	0.208	0.043	0.978	0.957	0.212	4.326*	0.231*
SAT_VENT	0.408†	0.861‡	0.264	0.070	0.964	0.930	0.274	7.195*	0.139
SAT_LIGHT	0.202†	0.695	0.182	0.033	0.983	0.967	0.185	3.280*	0.305*
OES	0.240†	0.740	0.197	0.039	0.980	0.961	0.200	3.840*	0.260*
JOBSATIS	0.308†	0.800	0.223	0.050	0.975	0.950	0.229	5.008*	0.200

Note. † ICC(1) >= .12. ‡ ICC(2) >= .85. ** E <= .58 indicates independence * $p <= .05$.

Overall, none of the five dependent variables met all four criteria for group effects. Therefore, we concluded that the assumption that observations were independent of building was met. Further analyses proceeded by combining all cases in one group, ignoring building effects.

3.2.3 Hierarchical regression models. The regression models were hierarchically structured. For all analyses, demographic control variables were entered on Step One as a block. These comprised sex (coded 0 or 1 for male or female), age (five categories entered as a continuous variable), and job type. Job type had four categories entered as three dummy codes: Admin where 1 = administrative, 0 = other; Prof where 1 = professional, 0 = other; and, Mgr, where 1 = managerial and 0 = other. The fourth category was technical.

The order of entry of the other variables in each analysis was determined based on theoretical considerations and on guidance from the literature. Our first interest was in gross descriptors of the workstation: workstation area, partition height, enclosure, and presence of a window. These are likely to be the most salient characteristics for occupants. Therefore, we examined the effects of workstation characteristics on all dependent variables.

The workstation characteristics were correlated with physical conditions. These relationships were examined separately and reported by Newsham et al. (2003a). For the regressions on satisfaction outcomes, we decided to control first for these workstation characteristics before adding measured physical conditions to the models. Thus, we controlled for the most salient workstation characteristics before looking to see whether the physical conditions themselves predicted additional variance. The models differed for each subset of environmental satisfaction. Thus, for Sat_Priv we looked for additional variance explained by acoustic conditions. For Sat_Light we looked at lighting conditions. For Sat_Vent we looked at ventilation and IAQ conditions. We looked at all of the physical condition models as predictors of OES and JobSatis.

3.3 Predicting Satisfaction with Privacy

3.3.1 Workstation characteristics. Satisfaction with privacy was first regressed on workstation characteristics. For this analysis the sample size was 757 after removing cases with missing data and univariate outliers. After the control variables, workstation area (SQRTAREA) was entered as the next step, followed by enclosure (MONPH_NOOPEN and PANELS_CAT). WINDOW was the final step. Table 11 summarizes the result of this hierarchical regression.

Table 11. *Summary table for Sat_Priv regressed on workstation characteristics.*

	β	β	β	β
AGE_COMBINED	-.107**	-.139***	-.135***	-.131***
GENDER	.066	.057	.055	.056
ADMIN	.127**	.081	.084	.084
MGR	.009	-.008	-.007	-.004
PROF	.043	-.002	.000	-.001
SQRTAREA		.145***	.149**	.178**
MINPH_NOOPEN			.014	.007
PANELS_CAT			-.029	-.035
WINDOW				-.053
R^2 change	.020*	.018***	.001	.002
Total R^2	.020*	.038***	.038***	.041***
Adjusted R^2	.013*	.030***	.028***	.029***

Note. N=757. * *p*<=.05. ***p*<=.01. ****p*<=.001.

The overall model was statistically significant at all steps. Of the control variables, age persisted as a significant predictor, with younger people reporting greater satisfaction with privacy. In the first step, administrators also showed greater satisfaction with privacy, but this variable dropped out when the workstation characteristics were added. Workstation area was a significant predictor in all steps and uniquely explained 1.8% of the variance. As expected, larger workstations predicted greater satisfaction with privacy. Neither of the enclosure variables predicted satisfaction with privacy, but it would be premature to conclude that enclosure is not important because of their high correlation with workstation area (Table 8). Area is a strong predictor in this equation and could be carrying the variance for both the size and degree of enclosure.

3.3.2 Acoustic conditions. We next looked for additional predictive power from the three physical aspects of the acoustic environment: ambient noise (LNOISEA), speech intelligibility (SII), and the relative spectral properties of the ambient noise

(LOHI_DBA).

For LNOISEA and LOHI_DBA, we thought it possible that the relationships might take a quadratic rather than a linear shape, with an intermediate value being optimal (i.e., neither too loud nor too soft, neither too rumbly nor too hissy). However, individual regressions of Sat_Priv against the quadratic shape for either LNOISEA or LOHI_DBA (always controlling for the five demographic variables first), showed no evidence of a quadratic trend. Therefore we proceeded with linear terms only.

The model entered SII first, after the control variables and the workstation characteristics. Conversations from others are among the most frequent noise-related complaints in open-plan offices (Navai & Veitch, 2003), and we expected this to be the strongest predictor. The overall level of background noise followed, and lastly the indicator of its spectral properties. The sample size was 694 after removing cases with missing data and outliers; as noted above, some of the acoustic variables had a large amount of missing data. Table 12 summarizes the result.

Table 12. *Summary table for Sat_Priv regressed on workstation characteristics and acoustic conditions.*

	β	β	β	β	β
AGE_COMBINED	-.111**	-.135***	-.128***	-.126**	-.128***
GENDER	.072	.063	.065	.066	.065
ADMIN	.152**	.108*	.103*	.103	.102
MGR	.032	.020	.015	.011	.010
PROF	.067	.023	.028	.029	.031
SQRTAREA		.175**	.184**	.194**	.207***
MINPH_NOOPEN		.012	.002	.015	.017
PANELS_CAT		-.023	-.047	-.036	-.022
WINDOW		-.072	-.070	-.080	-.091*
SII			-.071	-.038	-.012
LNOISEA				.046	.055
LOHI_DBA					-.046
R^2 change	.022**	.022**	.004	.001	.001
Total R^2	.022**	.044***	.048***	.049***	.050***
Adjusted R^2	.015**	.031***	.034***	.034***	.034***

Note. N=694. * p<=.05. **p<=.01. ***p<=.001.

The final model was statistically significant and explained more variance than the model with workstation characteristics only. Age and workstation area remained statistically significant predictors. In this model, with acoustic conditions controlled, presence of a window also significantly predicted satisfaction with privacy, in an inverse direction: those with windows were less satisfied. The acoustic conditions themselves were not statistically significant predictors of satisfaction with privacy.

3.3.3 Discussion: Satisfaction with privacy. In our data set, satisfaction with privacy was influenced by age, workstation area, and the presence of a window. Overall, only 5% of the variance in satisfaction with privacy was explained, which is a small effect size (Cohen, 1988).

Having a window reduced satisfaction with privacy to a small degree. This relationship emerged only when acoustic predictors were added to the model. It is possible that visual privacy might be compromised by a window, depending on the surroundings and the availability of blinds to control the view in. Alternatively, it is possible that a window provides a hard reflective surface that could allow more speech transmission from one workstation to another, thereby reducing speech privacy. This is consistent with the physics of sound transmission, but we know of no other satisfaction study to report such an effect.

It was not surprising to find that workstation area significantly predicted satisfaction with privacy. Larger workstations place occupants farther apart, reducing the number of people available to overhear conversations and the number of sources of unwanted sound. The finding is consistent with other investigations, in which workplace satisfaction was greater when workstation areas were larger (Brill et al., 1984; O'Neill & Carayon, 1993; Sundstrom, Town, Brown, Forman, & McGee, 1982; Sutton & Rafaeli, 1987). Other investigations have reported separately for different job types, finding differences between them; our regression model controls for job type, yet finds the relationship nonetheless.

However, we did not find that enclosure, whether in the form of partition height or number of panels, predicted satisfaction with privacy. In this we failed to replicate previous findings that have focused on privacy as an outcome (O'Neill & Carayon, 1993; Sundstrom et al., 1980; Sundstrom et al., 1982). Two reasons might explain this. First, the high correlation between workstation area and partition height probably obscured the relationship. Second, there was little variance in the two-level categorical variable for degree of enclosure (PANELS_CAT). However, it is also possible that any partition that is not a full wall, regardless of its height, has the same effect on satisfaction with privacy (Kupritz, 2003a).

The finding that age negatively predicted satisfaction with privacy is an intriguing one with parallels in other research using qualitative methods. Kupritz (2003a) found that older workers associated having a larger office with talking privately with people, whereas younger workers did not. They also associated office location with minimizing disruptions. Privacy needs appeared to change with age, although experience rather than age *per se* might provide the better explanation. Given the prevalence of open-plan offices, it is possible that younger employees have had less exposure to more enclosed workplaces than older ones, and have therefore formed difference associations and expectations.

3.4 Predicting Satisfaction with Lighting

3.4.1 Workstation characteristics. For this analysis, the sample size was 758 cases after excluding cases with missing data and outliers. Table 13 shows the result of the analysis.

Table 13. *Summary table for Sat_Light regressed on workstation characteristics.*

	β	β	β	β
AGE_COMBINED	.017	.004	-.003	-.027
GENDER	.055	.051	.048	.043
ADMIN	.086	.068	.067	.069
MGR	.045	.038	.030	.015
PROF	.018	.000	.006	.009
SQRTAREA		.059	.163**	.021
MINPH_NOOPEN			-.135**	-.097*
PANELS_CAT			-.034	-.001
WINDOW				.259***
R^2 change	.007	.003	.012**	.053***
Total R^2	.007	.010	.022*	.075***
Adjusted R^2	.000	.002	.012*	.064***

Note. N=758. * p<=.05. ** p<=.01. *** p<=.001.

The final model was statistically significant and explained 7.5% of the variance, which is a small-to-medium effect size (cf. Cohen, 1988). At the final step, with WINDOW added, two predictors were statistically significant: WINDOW and MINPH_NOOPEN. Both were in the expected directions: People with a window were more satisfied with their lighting, and people with lower partitions were more satisfied. Lower partition heights allow more daylight penetration to interior workstations (Reinhart, 2002) and improve electric light distribution (Newsham & Sander, 2003), so these effects are internally consistent.

At the intermediate step, before the addition of WINDOW, both workstation area and partition height were statistically significant predictors. Workstation area dropped out at the final step, and the regression weight for partition height also became smaller. These changes reflect the power of the WINDOW variable and the intercorrelations between the three variables. Workstation area is correlated with both partition height and presence of a window. Presence of a window has the strongest relation to satisfaction with lighting.

3.4.2 Lighting conditions. As for the acoustic conditions, we repeated the above analysis with additional steps for measured lighting conditions. We conducted three variations. First, we examined the result for all the workstations considered together. In this analysis we used the variable NO_DL_WI instead of the simple window/no window coding of the WINDOW variable, to account for variations in the amount of daylight that might reach a workstation adjacent to, but not having, a window.

Next, we pulled out a subset consisting only of interior workstations in which no daylight could be present (those more than 15’ or 5 m from a window, NO_DL_WI = 0), and repeated the regression model (omitting, of course, NO_DL_WI as a predictor). We finally looked at the outcome for those workstations with either daylight or a window. The purpose of the regressions on the subsets was to determine whether the effects of various physical conditions model would change for occupants with no window access or daylight, relative to those with. In addition, the no-daylight model has the closest relation to physical conditions predicted by the COPE software (Newsham & Sander, 2003).

Table 14 shows the result for the overall regression, with all workstations and controlling for workstation characteristics. Although other workstation characteristics analyses had WINDOW entered with workstation size and partition height, in this case we entered it last and use the NO_DL_WI variable instead. In this analysis we first wanted to see what effect the measured lighting conditions would have, regardless of whether or not a window or daylight were present. The order of entry was determined on theoretical grounds. Each variable was a separate step. We considered that reflected images in the VDT screen might be most detrimental to satisfaction, following results obtained by Veitch and Newsham (2000). The illumination level, indexed by CUBEDAYT, entered next, as an indicator of the adequacy of the amount of light available to see. Uniformity was the third lighting variable, its importance being reflected in codes and standards (e.g., CIBSE, 1994). Directionality was the fourth variable, added because previous NRC research has suggested that it influences satisfaction with lighting (Newsham, Marchand, Svec, & Veitch, 2002). NO_DL_WI was the fifth, and last, lighting variable in this overall model. (Entering it last also facilitated comparisons with the subsample models, discussed below.)

Table 14. *Summary table for Sat_Light regressed on workstation characteristics and lighting conditions.*

	β	β	β	β	β	β	β
AGE_COMBINED	.027	.009	.009	.008	.014	.008	-.009
GENDER	.045	.038	.038	.032	.030	.036	.037
ADMIN	.083	.065	.063	.055	.063	.067	.082
MGR	.037	.023	.022	.016	.017	.009	.002
PROF	.000	-.012	-.015	-.026	-.027	-.028	-.011
SQRTAREA		.170***	.177***	.127*	.126*	.122*	.046
MINPH_NOOPEN		-.139**	-.135**	-.089	-.089	-.068	-.078
PANELS_CAT		-.040	-.042	-.033	-.030	-.024	-.010
VDT_CAT			-.093**	-.080*	-.092*	-.101**	-.104**
CUBEDAYT				.123**	.119**	.086*	-.008
UNIFDAYT					-.081*	-.113**	-.108**
EH2V						-.098*	-.013
NO_DL_WI							.281***
R^2 change	.008	.017**	.009**	.013**	.006*	.007*	.049***
Total R^2	.008	.024*	.033**	.046***	.052***	.059***	.108***
Adjusted R^2	.001	.014*	.021**	.033***	.038***	.044***	.092***

Note. N = 740. * p<=.05. **p<=.01. ***p<=.001.

The control variables alone (step one) were not significant predictors of satisfaction with lighting, but every other step achieved statistical significance. Workstation area was a significant predictor until the last step. Of the lighting variables, each added statistically significant amounts of explained variance on the step in which they entered. Each appears to have a role in explaining the variance in satisfaction with lighting. Lower levels of reflected images in computer screens, higher average global light levels, and greater desktop uniformity are all associated with higher satisfaction with lighting. Lower ratios of horizontal to vertical illuminance (EH2V) are associated with higher satisfaction (i.e., relatively more vertical than horizontal). However, at the final step with NO_DL_WI added, only VDT_CAT and uniformity remain along with NO_DL_WI as significant predictors. This final variable explains the largest amount of variance and has the largest standardized β weight. Having daylight or having a window each improve satisfaction with lighting. Relatively smaller beneficial effects are associated with lower VDT glare and greater uniformity (recall that the variable UNIFDAYT is reverse-scored, so that lower values are more uniform lighting).

Next, we separated the sample into two groups. Descriptive statistics for the three groups on the variables in this analysis are shown in Table 15. Between-group differences are apparent. Peripheral workstations are somewhat larger, have higher illuminance levels, and lower ratios of horizontal to vertical illuminance, than central workstations. The illuminance level and directionality differences are consistent with having windows providing daylight.

Table 15. *Descriptive statistics for full sample and lighting subgroups.*

	Full Sample			Central WS			Peripheral WS		
	M	*SD*	N	*M*	*SD*	N	*M*	*SD*	N
SAT_LIGHT	4.75	1.20	740	4.40	1.16	312	5.03	1.14	427
AGE_COMBINED	2.62	.95	740	2.50	.99	312	2.72	.91	427
GENDER	1.52	.50	740	1.52	.50	312	1.52	.50	427
ADMIN	.27	.44	740	.28	.45	312	.27	.44	427
MGR	.09	.28	740	.05	.21	312	.11	.32	427
PROF	.39	.49	740	.39	.49	312	.38	.49	427
SQRTAREA	8.88	2.02	740	8.55	1.99	312	9.16	1.98	427
MINPH_NOOPEN	60.79	9.46	740	61.38	9.89	312	60.46	9.06	427
PANELS_CAT	1.74	.44	740	1.73	.44	312	1.75	.43	427
VDT_CAT	1.92	.88	740	1.90	.86	312	1.93	.90	427
CUBEDAYT	241.53	149.72	740	168.94	67.58	312	296.76	172.05	427
UNIFDAYT	.44	.20	740	.43	.21	312	.44	.19	427
EH2V	2.32	.82	740	2.68	.79	312	2.06	.74	427
NO_DL_WI	.98	.91	740						
WINDOW							.70	.46	427

Note. Central workstations had NO_DL_WI = 0. There were 330 of these in the full COPE sample. Peripheral workstations had NO_DL_WI = 1 or 2. There were 449 of these in the full COPE sample.

Table 16 reports the result of the regression analysis for the Central workstations. Although the model was statistically significant for steps 2-6, only one step added significantly to the explained variance, and only one variable was itself a statistically significant predictor. For those workstations without any daylight, the ratio of horizontal to vertical illuminance was a significant predictor of satisfaction with lighting. The direction of the effect differed from the overall analysis. In this case, higher ratios were more satisfactory, indicating a preference for higher horizontal illuminance than vertical.

Table 16. *Central workstations' summary table for Sat_Light regressed on workstation characteristics and lighting conditions.*

	β	β	β	β	β	β
AGE_COMBINED	-.006	-.010	-.013	-.013	-.007	.000
GENDER	.023	.006	.005	.009	.001	-.002
ADMIN	.072	.102	.109	.111	.115	.111
MGR	.034	.045	.045	.053	.054	.058
PROF	-.113	-.060	-.048	-.060	-.057	-.060
SQRTAREA		-.053	-.046	-.068	-.091	-.099
MINPH_NOOPEN		-.146	-.144	-.117	-.113	-.163
PANELS_CAT		.098	.094	.092	.097	.067
VDT_CAT			-.072	-.078	-.087	-.072
CUBEDAYT				.092	.056	.006
UNIFDAYT					-.086	-.042
EH2V						.179**
R^2 change	.027	.023	.005	.008	.005	.020**
Total R^2	.027	.050*	.055*	.063*	.069*	.088**
Adjusted R^2	.011	.025*	.027*	.032*	.034*	.052**

Note. N = 312. * p<=.05. **p<=.01. ***p<=.001.

For the Peripheral workstations we repeated the order of entry that was used for the Central workstations, then entered WINDOW as a final step. This provided a contrast between actually having a window in the workstation (as was the case for 70% of peripheral workstations), and having daylight but no window. The results are shown in Table 17.

Table 17. *Peripheral workstations' summary table for Sat_Light regressed on workstation characteristics and lighting conditions.*

	β	β	β	β	β	β	β
AGE_COMBINED	-.020	-.041	-.035	-.035	-.032	-.037	-.040
GENDER	.060	.026	.027	.025	.021	.041	.041
ADMIN	.097	.060	.048	.047	.057	.064	.067
MGR	.049	.033	.027	.026	.022	.007	.009
PROF	.087	.072	.052	.052	.049	.036	.038
SQRTAREA		.196**	.200**	.196**	.215**	.209**	.174*
MINPH_NOOPEN		-.045	-.042	-.038	-.040	-.019	-.030
PANELS_CAT		-.116*	-.113*	-.112*	-.108	-.110*	-.100
VDT_CAT			-.109*	-.107*	-.121*	-.139**	-.136**
CUBEDAYT				.012	.018	-.047	-.061
UNIFDAYT					-.121*	-.157**	-.158**
EH2V						-.149**	-.138*
WINDOW							.071
R^2 change	.007	.023*	.012*	.000	.013*	.015**	.003
Total R^2	.007	.030	.042*	.042	.055*	.070**	.073**
Adjusted R^2	-.005	.012	.021*	.019	.030*	.043**	.044**

Note. N = 427. * p<=.05. **p<=.01. ***p<=.001.

For people with access to daylight or a window, although overall somewhat less variance was explained the result is more interpretable than for the Central workstations. At the end of the sixth step, without WINDOW, the model for peripheral workstations is the same as that for central workstations. Here, workstation size, the number of panels, VDT glare, uniformity and directionality were all statistically significant predictors. Satisfaction with lighting increased with larger workstations, fewer panels, lower VDT glare, greater uniformity, and lower horizontal-to-vertical illuminance ratios. The addition of the WINDOW variable on the following step did not add significantly to the explained variance and changed the pattern of predictor significance only for one variable: the number of panels was no longer statistically significant. This suggests that for people with some daylight, it is the physical properties of the luminous environment that principally influence satisfaction with lighting, rather than the qualities that are specific to the window, such as the view of outside that it affords.

3.4.3 Discussion: Satisfaction with lighting. The effect size for satisfaction with lighting falls between the ranges of small and medium-sized effects, with 10.8% of the variance explained when all workstations were considered. Slightly less variance was explained for the central (8.8%) and peripheral (7.3%) workstations considered separately.

The dominant finding here is the importance of a window to satisfaction with lighting. In the workstation characteristics regression, presence of a window accounted for 5% of the variance in satisfaction with lighting, which is half of the total explained. In the form of a continuous variable that included the availability of daylight, it accounted for 5% over and above other workstation characteristics and physical measurements of lighting conditions (in the full sample regression with lighting characteristics). Having a window, or having access to daylight, improves satisfaction with lighting. Other researchers, with other dependent measures, have also found that windows are desirable to occupants (e.g., Finnegan & Solomon, 1981; Heerwagen & Heerwagen, 1986), and that people believe that working under natural daylight is better for health and well-being than electric light (Veitch & Gifford, 1996; Veitch, Hine, & Gifford, 1993).

Satisfaction with lighting was also a function of reflected images in VDT screens (higher values being worse), which is what lighting research and common sense would both predict (Veitch & Newsham, 1998; Veitch & Newsham, 2000). Its failure to predict satisfaction with lighting for the central workstations might have been caused by the lower incidence of high-glare workstations in that subsample (see Table 15). For both the peripheral workstations and the full sample, this categorical variable was an important predictor, explaining over 1% of the variance (out of a total of 7.3% for the peripheral workstations, and 10.8% for the full sample).

Uniformity predicted satisfaction with lighting for the full sample and the peripheral workstations; people preferred more uniformity. This might reflect a desire among those with daylight to avoid very nonuniform areas or very high contrasts between direct sunlight and shadow. We know of no studies of desktop uniformity in windowed spaces. However, Bernecker, Davis, Webster and Webster (1993) found that the luminance of horizontal and vertical surfaces, rather than desktop uniformity, predicted visual comfort, a variable that would be expected to correlate highly with satisfaction. Boyce and Slater (1990) found that few people found a nonuniform desk surface to be unacceptable. Uniformity did not predict satisfaction for the central workstations in the present study, although that might have been related to the smaller sample size.

The finding that directionality expressed as the ratio of horizontal to vertical illuminance predicted satisfaction with lighting is new; to our knowledge only one report, a pilot study, has previously used this ratio (Newsham et al., 2002). The change in direction from peripheral to central workstations is very intriguing. It appears that for central workstations, satisfaction increases as the horizontal component increases; whereas for peripheral workstations satisfaction increases as the vertical component increases. It might be the case that when daylight is available through a window (a vertical source for all of our buildings), people prefer that as the principal light source. It is unclear why the preferred directionality would change for windowless workstations, unless it is the case that when the light source is more directly down there is less possibility of reflections in the VDT screen.

For peripheral workstations only, workstation area was positively related to satisfaction with lighting. Perhaps a larger workstation also means a larger window, which some have found to be preferred for lighting and view (Cuttle, 1983; Keighley, 1973a, 1973b; Roche, Dewey, & Littlefair, 2000).

3.5 Predicting Satisfaction with Ventilation

3.5.1 Workstation characteristics. As for satisfaction with privacy and satisfaction with lighting, we first examined the effects of workstation characteristics on satisfaction with ventilation. The results of this regression analysis are shown in Table 18. The sample size was 757 after cases having missing data and outlying cases were excluded. The model was statistically significant at all steps, and the overall percentage of variance showed a medium-sized effect of 9.6% explained variance. Although workstation size contributed significantly when it was entered on the second step, it was not statistically significant in the final model. This indicates that partition height, to which it was strongly correlated, is the more important predictor of satisfaction with ventilation. Higher partitions are associated with lower satisfaction with ventilation, as is the presence of a window. Women tend to have lower satisfaction with ventilation than men.

Table 18. *Summary table for Sat_Vent regressed on workstation characteristics.*

	β	β	β	β
AGE_COMBINED	-.054	-.017	-.026	-.017
GENDER	.192***	.204***	.202***	.203***
ADMIN	-.057	-.004	-.006	-.006
MGR	.005	.026	.017	.023
PROF	.004	.058	.062	.061
SQRTAREA		-.171***	-.068	-.018
MINPH_NOOPEN			-.142**	-.156***
PANELS_CAT			-.020	-.032
WINDOW				-.093*
R^2 change	.051***	.025***	.012**	.007*
Total R^2	.051***	.077***	.089***	.096***
Adjusted R^2	.045***	.069***	.079***	.085***

Note. N=757. * p<=.05. **p<=.01. ***p<=.001.

3.5.2 Ventilation/IAQ conditions. We report here our tests of the additional variance explained by ventilation conditions using the measured values. We also converted the physical conditions to derived indices for thermal comfort and draught, and report that regression in Appendix A. Table 19 shows the regression results for ventilation and IAQ conditions added after workstation characteristics. This analysis had 721 cases after outliers and cases having missing data were excluded. Only linear effects appear in this model; preliminary regressions of ventilation conditions alone revealed no evidence of quadratic relations, although these might have been expected.

Table 19. *Summary table for Sat_Vent regressed on workstation characteristics and ventilation conditions.*

	β	β	β	β	β
AGE_COMBINED	-.050	-.012	-.021	-.021	-.012
GENDER	.179***	.191***	.220***	.218***	.228***
ADMIN	-.055	.003	-.023	-.023	-.023
MGR	.022	.041	.018	.025	.006
PROF	.005	.067	.055	.056	.062
SQRTAREA		-.032	-.055	-.071	-.066
MINPH_NOOPEN		-.161***	-.182***	-.192***	-.168***
PANELS_CAT		-.022	-.032	-.030	-.034
WINDOW		-.096*	-.108**	-.111**	-.119**
AIR_V_H			-.098**	-.103**	-.111**
RTD_H			-.144***	-.139***	-.121**
REL_HUMID			.052	.053	.096
DL_OUT				-.057	-.062
FDCO2					-.124***
POLLUT					-.047
R^2 change	.046***	.049***	.029***	.003	.016**
Total R^2	.046***	.096***	.125***	.127***	.143***
Adjusted R^2	.039***	.084***	.110***	.111***	.125***

Note. N=721. * $p<=.05$. ** $p<=.01$. *** $p<=.001$.

The results show statistically significant models at all steps, with only diffuser location failing to add to the explained variance. In the final model, three of the physical conditions were statistically significant predictors, over and above the three previously identified. As seen above, men were more satisfied with ventilation conditions than women, and people with lower partitions or without a window were also more satisfied. In addition, lower air velocity (AIR_V_H) and lower temperatures (RTD_H) were associated with higher satisfaction with ventilation, as was lower carbon dioxide concentration.

3.5.3 Discussion: Satisfaction with ventilation. The regressions for satisfaction with ventilation explained a total of 14.3% of the variance when both workstation characteristics and physical conditions were in the model, bringing it into the range of a medium-sized effect. Gender was a significant predictor, with women being less satisfied than men. This is typical of research in this area (Hedge et al., 1992; Molhave, Jensen, & Larsen, 1991; O'Neill, 1992; Zweers, Preller, Brunekreef, & Boleij, 1992).

Even controlling for these demographic variables, workstation characteristics were significant predictors of satisfaction with ventilation. Lower partition heights increased satisfaction with ventilation. This finding is intriguing, given that engineering research has found no relationship between partition heights and ventilation effectiveness (Haghighat, Huo, Zhang, & Shaw, 1996; Shaw, MacDonald, Galasiu, Reardon, & Won, 2003). Perhaps the effect on satisfaction is an inference from what is observable, rather than a reflection of physical conditions.

The presence of a window also negatively affected satisfaction with ventilation, and this relationship strengthened (as indicated by a larger β weight) when physical conditions, including temperature, were controlled. Although the temperature at the time of measurement was controlled in the regression equation, it seems possible that the satisfaction rating would be influenced by the overall experience of more variable temperatures near a window, with heat gain during times of direct sun and the possibility of radiant cooling during winter months. This would be consistent with observations in UK buildings by Roche, Dewey, and Littlefair (2000), who found that the upper limit of acceptable window size was reached when it led to problems with thermal regulation.

Over and above workstation characteristics, physical conditions predicted satisfaction with ventilation. Both air movement and temperature showed negative relationships to satisfaction with ventilation, indicating that people neither want to be too hot nor to experience high air movement. Within the range of these variables that we observed, these relationships are consistent with expectations (ASHRAE, 1997; Fanger, 1982). Both variables would be expected to show quadratic relationships with an optimum middle level, but we appear not to have sampled the full range needed to demonstrate this shape.

We also found that people are sensitive to carbon dioxide concentration, with satisfaction with ventilation increasing as carbon dioxide levels dropped. Although the direction of the effect was predicted, it is most interesting that it was observable at the CO_2 concentrations measured here. Current North American recommendations cite 1000 ppm as the permissible limit, above which satisfaction would be expected to decline (ASHRAE, 2001), but in our sample we detected evidence of declining satisfaction even at lower concentrations; the median value in our sample was 639 ppm (Table 7, above).

3.6 Predicting Overall Environmental Satisfaction

3.6.1 Workstation characteristics. We had previously validated a model in which the individual components of environmental satisfaction predicted overall environmental satisfaction (OES). This suggests that workstation characteristics and physical conditions would influence OES indirectly; nonetheless, we also looked for direct effects of workstation characteristics and physical conditions on OES. The regression model for OES regressed on workstation characteristics is shown in Table 20. There were 733 cases in this regression, after excluding cases having missing data and outliers.

Table 20. *Summary table for OES regressed on workstation characteristics.*

	β	β	β	β
AGE_COMBINED	-.033	-.033	-.040	-.038
GENDER	.052	.052	.050	.051
ADMIN	.064	.063	.064	.064
MGR	-.040	-.040	-.048	-.047
PROF	-.080	-.081	-.075	-.075
SQRTAREA		.003	.101	.110
MINPH_NOOPEN			-.129**	-.132**
PANELS_CAT			-.026	-.029
WINDOW				-.018
R^2 change	.017*	.000	.011*	.000
Total R^2	.017*	.017*	.028**	.028*
Adjusted R^2	.010*	.009*	.017**	.016*

Note. N=733. * $p<=.05$. ** $p<=.01$. *** $p<=.001$.

The direct effect of workstation characteristics on OES was small, with only 2.8% of the variance explained at the final step. Partition height (MINPH_NOOPEN) was the only statistically significant predictor, and it accounted independently for only 1.1% of the explained variance.

3.6.2 Acoustic conditions. The regression of OES on workstation characteristics and acoustic conditions is summarized in Table 21. The sample size, after dropping cases with missing data and outliers, was 671. There was no evidence of direct effects of acoustic conditions on OES; none of the regression steps had a significant model. Indeed, in this analysis even partition height was not predictive. The reduced sample size might explain this.

Table 21. Summary table for OES regressed on workstation characteristics and acoustic conditions.

	β	β	β	β	β
AGE_COMBINED	-.026	-.027	-.028	-.025	-.024
GENDER	.053	.053	.053	.053	.053
ADMIN	.096	.093	.093	.093	.094
MGR	-.012	-.018	-.018	-.022	-.021
PROF	-.052	-.050	-.050	-.049	-.053
SQRTAREA		.075	.074	.086	.068
MINPH_NOOPEN		-.098	-.097	-.082	-.085
PANELS_CAT		-.008	-.007	.008	-.010
WINDOW		-.036	-.036	-.048	-.033
SII			.005	.045	.009
LNOISEA				.057	.045
LOHI_DBA					.061
R^2 change	.016	.006	.000	.001	.003
Total R^2	.016	.022	.022	.023	.026
Adjusted R^2	.009	.009	.007	.007	.008

Note. N = 671.

3.6.3 Lighting conditions. We conducted three regression analyses for OES involving workstation characteristics and lighting conditions. As before, we looked first at the whole sample and then at the effects on central and peripheral workstations.

Table 22 summarizes the results for the full sample, of which 706 remained after excluding cases having missing data and outliers. The model achieved statistical significance at each step, and added slightly to the percentage of explained variance over the workstation characteristics model. Only partition height was a statistically significant predictor at any step. When lighting conditions were controlled, higher partitions were still associated with lower overall environmental satisfaction.

Table 22. Summary table for OES regressed on workstation characteristics and lighting conditions.

	β	β	β	β	β	β	β
AGE_COMBINED	-.045	-.049	-.049	-.050	-.048	-.048	-.050
GENDER	.051	.050	.050	.047	.046	.047	.047
ADMIN	.061	.063	.063	.059	.063	.064	.064
MGR	-.049	-.056	-.056	-.058	-.058	-.058	-.059
PROF	-.084	-.076	-.077	-.081	-.082	-.082	-.081
SQRTAREA		.091	.092	.073	.072	.072	.066
MINPH_NOOPEN		-.134**	-.134**	-.115*	-.115*	-.113*	-.114*
PANELS_CAT		-.023	-.023	-.020	-.019	-.018	-.017
VDT_CAT			-.013	-.008	-.013	-.014	-.014
CUBEDAYT				.049	.047	.045	.037
UNIFDAYT					-.039	-.042	-.041
EH2V						-.008	-.001
NO_DL_WI							.023
R^2 change	.019*	.011*	.000	.002	.001	.000	.000
Total R^2	.019*	.031**	.031**	.033**	.034*	.034*	.035*
Adjusted R^2	.012*	.020**	.018**	.019**	.019*	.018*	.017*

Note. N = 716. * $p<=.05$. ** $p<=.01$. *** $p<=.001$.

We again split the sample into central and peripheral workstations. The between-groups descriptive statistics are shown in Table 23. There are small differences from the groups in the satisfaction with lighting analyses because of small differences in sample size. Although OES was slightly higher in peripheral workstations than central ones, we would not expect it to be a significant difference, given that WINDOW was not a significant predictor in the workstation characteristics regression, nor was NO_DL_WI in the full sample model for workstation conditions with lighting conditions.

Table 23. *OES descriptive statistics for full sample and lighting subgroups.*

	Full Sample			Central WS			Peripheral WS		
	M	*SD*	N	*M*	*SD*	N	*M*	*SD*	N
OES	4.05	1.31	716	3.95	1.27	303	4.15	1.33	412
AGE_COMBINED	2.62	.96	716	2.49	.99	303	2.72	.92	412
GENDER	1.53	.50	716	1.53	.50	303	1.53	.50	412
ADMIN	.27	.44	716	.27	.44	303	.26	.44	412
MGR	.09	.28	716	.05	.21	303	.11	.32	412
PROF	.40	.49	716	.40	.49	303	.40	.49	412
SQRTAREA	8.87	2.02	716	8.53	2.00	303	9.15	1.98	412
MINPH_NOOPEN	60.67	9.55	716	61.26	9.96	303	60.35	9.17	412
PANELS_CAT	1.74	.44	716	1.73	.45	303	1.75	.43	412
VDT_CAT	1.92	.89	716	1.90	.87	303	1.94	.90	412
CUBEDAYT	242.30	150.83	716	169.29	68.17	303	298.26	173.47	412
UNIFDAYT	.44	.20	716	.43	.22	303	.44	.19	412
EH2V	2.32	.82	716	2.66	.79	303	2.06	.74	412
NO_DL_WI	.97	.91	716						
WINDOW							.70	.46	412

Note. Central workstations had NO_DL_WI = 0. There were 330 of these in the full COPE sample. Peripheral workstations had NO_DL_WI = 1 or 2. There were 449 of these in the full COPE sample.

For the central workstations, the OES regression is summarized in Table 24. Although the model as a whole did not reach statistical significance on any step, there is one independent variable that was a significant predictor throughout. Professionals had lower OES than non-professionals in the central workstations. We suspect that this is an indication that people in this job class expect to have an office with a window, or at least access to daylight. The average illuminance on the cube (CUBEDAYT) added significantly to the percentage of variance explained on the step when it was added, but the overall equation still did not reach statistical significance.

Table 24. *Central workstations' summary table for OES regressed on workstation characteristics and lighting conditions.*

	β	β	β	β	β	β
AGE_COMBINED	.012	.017	.017	.017	.016	.016
GENDER	.030	.028	.028	.032	.034	.034
ADMIN	-.057	-.034	-.035	-.033	-.034	-.034
MGR	-.054	-.049	-.049	-.040	-.040	-.040
PROF	-.191**	-.160*	-.162*	-.178*	-.179*	-.179*
SQRTAREA		.043	.042	.012	.017	.017
MINPH_NOOPEN		-.106	-.107	-.068	-.070	-.070
PANELS_CAT		-.046	-.045	-.047	-.049	-.049
VDT_CAT			.011	.002	.005	.005
CUBEDAYT				.129*	.137*	.137
UNIFDAYT					.020	.020
EH2V						.016
R^2 change	.028	.010	.000	.015*	.000	.003
Total R^2	.028	.039	.039	.054	.055	.058
Adjusted R^2	.012	.013	.009	.022	.019	.019

Note. N = 303. * p<=.05. **p<=.01. ***p<=.001.

The results for peripheral workstations showed a different pattern from the central workstations. On step one, with only the control variables in the model, administrators show higher OES than non-administrators. This could be the converse to the effect in the central workstations: administrators might have higher OES because they do not expect to have peripheral workstations. In addition, older participants showed lower OES than younger ones, but only in this analysis. At the final step we see an interesting effect of adding WINDOW to the model. For people in peripheral workstations, the presence of a window leads to lower OES, whereas larger workstations lead to higher OES. The final model explained 6.3% of the variance in OES, a small effect but larger and more interpretable than when all the workstations were considered together.

Table 25. *Peripheral workstations' summary table for OES regressed on workstation characteristics and lighting conditions.*

	β	β	β	β	β	β	β
AGE_COMBINED	-.118*	-.118*	-.117*	-.117*	-.116*	-.117*	-.110*
GENDER	.063	.063	.063	.064	.063	.067	.066
ADMIN	.151*	.144*	.141*	.142*	.147*	.149*	.141*
MGR	.002	-.006	-.007	-.007	-.008	-.012	-.017
PROF	.012	.009	.005	.005	.004	.002	-.004
SQRTAREA		.060	.061	.064	.073	.071	.162*
MINPH_NOOPEN		-.100	-.099	-.103	-.105	-.099	-.069
PANELS_CAT		-.011	-.011	-.011	-.010	-.010	-.035
VDT_CAT			-.022	-.025	-.029	-.034	-.042
CUBEDAYT				-.011	-.009	-.023	.011
UNIFDAYT					-.049	-.058	-.053
EH2V						-.034	-.062
WINDOW							-.186**
R^2 change	.032*	.007	.000	.000	.002	.001	.021*
Total R^2	.032*	.038*	.039	.039	.041	.042	.063*
Adjusted R^2	.020*	.019*	.017	.015	.015	.013	.032*

Note. N = 412. * p<=.05. **p<=.01. ***p<=.001.

3.6.4 Ventilation/IAQ conditions. Table 26 shows the summary of the regression of OES on workstation characteristics and ventilation conditions, which included data from 697 cases. The model is statistically significant at all steps, although only two independent variables were statistically significant predictors. As expected, lower partition heights were associated with higher OES. In addition, people without an air supply diffuser in the workstation reported lower OES (DL_OUT).

Table 26. *Summary table for OES regressed on workstation characteristics and ventilation conditions.*

	β	β	β	β	β
AGE_COMBINED	-.026	-.030	-.034	-.033	-.029
GENDER	.045	.045	.051	.048	.053
ADMIN	.072	.078	.060	.061	.061
MGR	-.028	-.032	-.042	-.028	-.037
PROF	-.083	-.072	-.077	-.073	-.070
SQRTAREA		.109	.101	.071	.071
MINPH_NOOPEN		-.141**	-.132*	-.149**	-.138*
PANELS_CAT		-.039	-.047	-.042	-.044
WINDOW		-.026	-.030	-.035	-.039
AIR_V_H			-.020	-.030	-.034
RTD_H			-.060	-.050	-.041
REL_HUMID			.051	.052	.069
DL_OUT				-.107**	-.111**
FDCO2					-.064
POLLUT					-.015
R^2 change	.018*	.013	.006	.009**	.004
Total R^2	.018*	.031**	.037**	.047**	.051**
Adjusted R^2	.011	.019	.020	.028	.030

Note. N=697. * $p<=.05$. ** $p<=.01$. *** $p<=.001$.

3.6.5 Discussion: Overall environmental satisfaction. The regressions for OES in general explain less variance than the regressions for satisfaction in specific domains (privacy, lighting, and ventilation), probably reflecting a mediated model. However, some of the significant predictors did not appear in the other regressions, so that the OES regressions extend our knowledge.

One particularly intriguing finding is the negative relationship between partition height and OES. Acoustic considerations had led us to predict that higher partitions would improve satisfaction with privacy (which it did not, see above) and, by extension, overall environmental satisfaction. Here, we found instead that lower partitions improved satisfaction. This finding is consistent with some investigations, but not others. Oldham (1988) found that office satisfaction (a comparable construct to our OES) increased for people who moved from a totally open (no partitions) office to an office with partitions varying between 48 and 72 inches; this finding is similar to the pattern observed by Mercer (1979). Conversely, Sundstrom et al. (1982) did not have a continuous measurement of partition height, but found that the number of enclosed sides with height greater than 72 inches was a significant predictor of workspace satisfaction for secretaries, bookkeepers, and accountants. In the original BOSTI study, Brill et al. (1984) reported that with workstation area held constant, enclosure (height and number of partitions together) was positively related to environmental satisfaction. However, Marans and Yan (1989) found that, in a model that first entered occupants' subjective ratings of workstation attributes, actual floor area and enclosure did not add significantly to the prediction of environmental satisfaction for occupants of open-plan offices. Moreover, subjectively rated noise and conversational privacy were relatively unimportant predictors of environmental satisfaction. Rated adequacy of the space and rated lighting quality were more important for open-plan office occupants.

Our findings are more similar to those of Marans and Yan (1989), in that the model with acoustic conditions added did not add to the prediction of OES over the workstation characteristics alone. Moreover, the partition height variable was not predictive of OES when lighting conditions were added. With ventilation conditions added, it remained predictive, along with the presence of an air supply in the workstation.

The descriptive statistics for the acoustic variables showed that speech intelligibility was generally high (see Table 5). If everyone had relatively less privacy than they had wanted, perhaps a small increase in partition height was not enough to improve overall environmental satisfaction. Lower partitions would, however, have provided greater access to daylight and might have led to perceptions of better air movement.

The effect of a window on OES for those peripheral workstations is noteworthy. For these people, OES was lower if the window was present in the workstation (as opposed to being within 15' or 5 m), but this model controlled for lighting conditions. This might provide an explanation for the finding that for people with a window, having a window is less important than for those who do not have a window (Boubekri & Haghighat, 1993). Although having a window provides a view of outdoors and lots of daylight, it can bring with it thermal problems. Controlling for the lighting effects of the window might be what allowed this dissatisfaction to become apparent. This explanation is consistent with the effects observed for satisfaction with ventilation.

We also found that having an air supply in the workstation was associated with higher environmental satisfaction, even when the physical conditions were also in the model. Thus, the effect is not a matter of the physical conditions being influenced by the location of the diffuser. It appears most likely that this is a psychological judgement in which environmental satisfaction increases when one can see that there is a direct supply of fresh air into the workstation. The literature does not appear to include other investigations that have considered this variable, so this finding awaits replication.

3.7 Predicting Job Satisfaction

3.7.1 Workstation characteristics. As for OES, we looked for direct effects of workstation characteristics on job satisfaction. These, analysed with a sample of 739, are shown in Table 27. The model was statistically significant at all steps, revealing interesting relationships. In every step, age is a significant predictor of job satisfaction: Younger workers are more satisfied with their jobs. This is a small effect, but explains half of the explained variance for the entire model. In step two, workstation area was a significant predictor of job satisfaction, although in an odd direction: Smaller workstations predicted greater job satisfaction. However, this effect disappeared after partition height entered the equation in step 3, indicating that of these two highly correlated variables, partition height is the more important predictor of job satisfaction. Lower partitions were associated with greater job satisfaction.

Table 27. *Summary table for JobSatis regressed on workstation characteristics.*

	β	β	β	β
AGE_COMBINED	-.127***	-.104**	-.108**	-.113**
GENDER	-.007	-.001	-.004	-.005
ADMIN	-.063	-.028	-.027	-.027
MGR	.002	.016	.009	.006
PROF	-.032	.002	.007	.007
SQRTAREA		-.111**	-.029	-.055
MINPH_NOOPEN			-.104*	-.097*
PANELS_CAT			-.032	-.026
WINDOW				.049
R^2 change	.021**	.011**	.007	.002
Total R^2	.021**	.031***	.039***	.041***
Adjusted R^2	.014**	.023**	.028***	.029***

Note. N = 739. * p<=.05. **p<=.01. ***p<=.001.

3.7.2 Acoustic conditions. As always, the sample size for job satisfaction regressions including the acoustic conditions had a smaller sample size (N=679) than the other models. For this analysis, the model was statistically significant at every step, but only age was a significant predictor (Table 28). The fact that neither partition height nor workstation area reached statistical significance in this regression suggests that the smaller sample size reduced statistical power to detect these small effects. In a larger sample we might have observed effects of acoustic conditions as well as workstation characteristics; indeed, some of the standardized regression weights (e.g., LNOISEA) were relatively large here, although not statistically significant.

Table 28. *Summary table for JobSatis regressed on workstation characteristics and acoustic conditions.*

	β	β	β	β	β
AGE_COMBINED	-.129***	-.112**	-.109**	-.104**	-.103*
GENDER	-.010	-.007	-.006	-.005	-.005
ADMIN	-.037	-.003	-.006	-.007	-.007
MGR	.038	.040	.038	.030	.030
PROF	-.015	.022	.024	.027	.026
SQRTAREA		-.078	-.073	-.049	-.056
MINPH_NOOPEN		-.074	-.080	-.047	-.049
PANELS_CAT		-.022	-.036	-.006	-.014
WINDOW		.060	.060	.035	.041
SII			-.041	.042	.027
LNOISEA				.119	.114
LOHI_DBA					.025
R^2 change	.020*	.019*	.001	.005	.000
Total R^2	.020*	.039**	.040**	.045***	.046**
Adjusted R^2	.013*	.026**	.026**	.030***	.029**

Note. N= 679. * p<=.05. **p<=.01. ***p<=.001.

3.7.3 Lighting conditions. Once again we examined both the models for the full sample, and for two subgroups. The results for the regression of job satisfaction on workstation characteristics and lighting conditions using the full sample are shown in Table 29. The model is statistically significant and explains a total of 4.2% of the variance, but in the final step the only statistically significant predictor is age. Partition height was statistically significant in steps two and three, but its variance spread over other variables in subsequent steps, leaving none sufficiently powerful to reach statistical significance at the final step.

Table 29. *Summary table for JobSatis regressed on workstation characteristics and lighting conditions.*

	β	β	β	β	β	β	β
AGE_COMBINED	-.127***	-.107**	-.107**	-.108**	-.109**	-.111**	-.115**
GENDER	-.002	.001	.001	-.001	.000	.002	.002
ADMIN	-.062	-.027	-.027	-.029	-.032	-.030	-.028
MGR	-.008	.000	.000	-.001	-.001	-.004	-.005
PROF	-.034	.004	.004	.001	.001	.001	.004
SQRTAREA		-.040	-.040	-.053	-.053	-.054	-.070
MINPH_NOOPEN		-.099*	-.099*	-.086	-.086	-.079	-.082
PANELS_CAT		-.021	-.021	-.019	-.020	-.018	-.015
VDT_CAT			-.007	-.003	-.001	-.004	-.005
CUBEDAYT				.033	.034	.024	.004
UNIFDAYT					.020	.009	.010
EH2V						-.031	-.014
NO_DL_WI							.059
R^2 change	.020**	.018**	.000	.001	.000	.001	.002
Total R^2	.020**	.038***	.038***	.039**	.039**	.040**	.042**
Adjusted R^2	.013**	.027***	.026***	.025**	.024**	.024**	.024**

Note. N = 721. * p<=.05. **p<=.01. ***p<=.001.

Overall and subgroup descriptive statistics for the variables in this analysis are shown in Table 30. The independent variables show small differences from the subgroup values for the satisfaction with lighting and OES regressions because of small differences in sample size. The small difference in job satisfaction between the groups would not be expected to be statistically significant, given the fact that NO_DL_WI was not a significant predictor in the overall regression model (Table 29), nor was WINDOW in the regression model for job satisfaction with workstation conditions alone (Table 27).

***Table 30**. JobSatis descriptive statistics for full sample and lighting subgroups.*

	Full Sample			Central WS			Peripheral WS		
	M	*SD*	N	*M*	*SD*	N	*M*	*SD*	N
JOBSATIS	5.14	.98	721	5.09	1.00	303	5.18	.97	417
AGE_COMBINED	2.63	.95	721	2.51	.98	303	2.72	.92	417
GENDER	1.52	.50	721	1.51	.50	303	1.53	.50	417
ADMIN	.27	.45	721	.28	.45	303	.27	.44	417
MGR	.08	.28	721	.05	.21	303	.11	.31	417
PROF	.38	.49	721	.39	.49	303	.38	.49	417
SQRTAREA	8.87	2.02	721	8.53	2.00	303	9.15	1.98	417
MINPH_NOOPEN	60.70	9.47	721	61.19	9.96	303	60.45	9.03	417
PANELS_CAT	1.74	.44	721	1.72	.45	303	1.75	.43	417
VDT_CAT	1.92	.88	721	1.88	.86	303	1.94	.90	417
CUBEDAYT	241.80	149.92	721	169.76	67.05	303	296.38	172.79	417
UNIFDAYT	.44	.20	721	.43	.21	303	.44	.19	417
EH2V	2.32	.82	721	2.68	.80	303	2.06	.74	417
NO_DL_WI	.98	.91	721						
WINDOW	5.14	.98	721				.70	.46	417

Note. Central workstations had NO_DL_WI = 0. There were 330 of these in the full COPE sample. Peripheral workstations had NO_DL_WI = 1 or 2. There were 449 of these in the full COPE sample.

The results for the central workstations show the effect of the smaller sample size and reduced statistical power. Although the percentage of explained variance is comparable to other models (4.2% in total), neither the model as a whole nor any of the independent variables is statistically significant. For people in central workstations it does not appear that lighting conditions directly influence job satisfaction.

Table 31. *Central workstations' summary table for JobSatis regressed on workstation characteristics and lighting conditions.*

	β	β	β	β	β	β
AGE_COMBINED	-.130*	-.110	-.112	-.112	-.112	-.110
GENDER	-.024	-.031	-.033	-.033	-.034	-.035
ADMIN	-.038	-.004	-.001	-.001	-.001	-.002
MGR	.021	.030	.030	.028	.028	.030
PROF	.002	.056	.062	.064	.065	.064
SQRTAREA		-.085	-.081	-.077	-.078	-.080
MINPH_NOOPEN		-.034	-.033	-.039	-.039	-.052
PANELS_CAT		-.056	-.059	-.058	-.057	-.065
VDT_CAT			-.041	-.039	-.040	-.036
CUBEDAYT				-.022	-.025	-.037
UNIFDAYT					-.006	.005
EH2V						.045
R^2 change	.020	.020	.002	.000	.000	.001
Total R^2	.020	.040	.041	.042	.042	.043
Adjusted R^2	.003	.014	.012	.009	.006	.003

Note. N = 303. * $p<=.05$. ** $p<=.01$. *** $p<=.001$.

For the peripheral workstations, the overall model was statistically significant at each step. However, the lighting conditions did not add any information to what was known from the regression of workstation characteristics alone. In the early steps, age and partition height were statistically significant predictors. Partition height ceased to be predictive as more variables were added into the model.

Table 32. *Peripheral workstations' summary table for JobSatis regressed on workstation characteristics and lighting conditions.*

	β	β	β	β	β	β	β
AGE_COMBINED	-.144**	-.114**	-.114*	-.114*	-.114*	-.116*	-.116*
GENDER	.004	.024	.024	.023	.023	.030	.030
ADMIN	-.089	-.055	-.056	-.056	-.058	-.056	-.056
MGR	-.024	-.016	-.017	-.017	-.016	-.021	-.021
PROF	-.066	-.044	-.045	-.045	-.045	-.049	-.049
SQRTAREA		-.066	-.065	-.068	-.072	-.073	-.081
MINPH_NOOPEN		-.129*	-.129*	-.127*	-.126*	-.120	-.122
PANELS_CAT		.016	.017	.017	.016	.015	.018
VDT_CAT			-.005	-.004	-.001	-.006	-.006
CUBEDAYT				.008	.007	-.013	-.016
UNIFDAYT					.023	.011	.011
EH2V						-.045	-.043
WINDOW							.016
R^2 change	.029*	.027**	.000	.000	.000	.001	.000
Total R^2	.029*	.056**	.056**	.056**	.057**	.058*	.058*
Adjusted R^2	.017*	.038**	.035**	.033**	.031**	.030*	.028*

Note. N = 417. * $p<=.05$. ** $p<=.01$. *** $p<=.001$.

3.7.4 Ventilation/IAQ conditions. The regression of job satisfaction on workstation characteristics and ventilation conditions had 703 cases after the exclusion of cases with missing data and outliers. The results are shown in Table 33. In addition to the effects of age and partition height, this model shows that air quality is a significant predictor of job satisfaction. Together the two variables that indicated the presence of air quality problems explained 2.1% of the variance, and both were statistically significant predictors in the final model, with higher pollutant levels leading to poorer job satisfaction. Moreover, the standardized regression weights show that they have comparable effects on predicted job satisfaction to the other significant predictors in the model (the Beta weights are all of the same order of magnitude, around .100).

Table 33. *Summary table for JobSatis regressed on workstation characteristics and ventilation conditions.*

	β	β	β	β	β
AGE_COMBINED	-.132***	-.121**	-.120**	-.120**	-.113**
GENDER	-.008	-.005	.002	.000	.007
ADMIN	-.055	-.021	-.019	-.019	-.022
MGR	.031	.033	.029	.037	.013
PROF	-.021	.018	.016	.018	.024
SQRTAREA		-.047	-.051	-.067	-.048
MINPH_NOOPEN		-.102*	-.123*	-.134*	-.107*
PANELS_CAT		-.021	-.019	-.017	-.020
WINDOW		.050	.048	.045	.030
AIR_V_H			-.018	-.023	-.034
RTD_H			-.024	-.019	-.002
REL_HUMID			-.029	-.028	.054
DL_OUT				-.062	-.061
FDCO2					-.121**
POLLUT					-.106*
R^2 change	.022**	.019**	.001	.003	.021***
Total R^2	.022**	.041***	.043**	.046**	.067***
Adjusted R^2	.015**	.029***	.026**	.028**	.046***

Note. N= 703. * *p*<=.05. ***p*<=.01. ****p*<=.001.

3.7.5 Discussion: Job satisfaction. Job satisfaction had been expected to show few direct relationships with workstation characteristics or physical conditions; we had expected the relationships to be indirect ones. Indeed, few such relationships were observed. Nonetheless, some of the relationships were of the same magnitude (5% variance explained) as for the domain-specific analyses above.

In the same manner as for overall environmental satisfaction, we were surprised to find that partition height showed a small, but statistically significant, negative relationship to job satisfaction. Lower partition heights were associated with higher job satisfaction, even after controlling for individual demographic characteristics. This finding is contrary to previous research, in which job satisfaction increased with the degree of enclosure (Oldham, 1988; Oldham & Brass, 1979; Sundstrom et al., 1980; Sundstrom et al., 1982). Because none of the earlier studies used measured partition height as a continuous independent variable, direct connections to our results are limited. Oldham and Fried (1987) found that enclosure did not influence job satisfaction in a main effect; rather, it interacted with the judged darkness of the workspace. Small, dark work spaces led to low job satisfaction. Interestingly, in our analysis, the effect of partition height disappeared when lighting characteristics were added to the model.

We did not find that acoustic conditions added to the prediction of job satisfaction. This is consistent with other investigations both in offices (Leather, Beale, & Sullivan, 2003) and in factories (Melamed, Fried, & Froom, 2001). However, other investigations have found that workplace noise levels interact with other job characteristics and stressors to influence job satisfaction. Our investigation did not include measurement of these variables; therefore we are unable to replicate the other results.

Surprisingly, the concentrations of both carbon dioxide and other pollutants were significant predictors of job satisfaction, even when workstation characteristics and other ventilation conditions were held constant. This finding is new, and worthy of further research attention.

Across all models we found that age was negatively related to job satisfaction. Younger people were more satisfied with their jobs than older people. Given the high mean value for job satisfaction, this finding does not mean that older people were dissatisfied, only that they were less satisfied. The literature on job satisfaction shows all manner of relationships to age, with relatively little support for simple linear effects (Bernal, Snyder, & McDaniel, 1998; Hochwarter, Ferris, Perrewe, Witt, & Kiewitz, 2001). It is possible that our sample represented the negatively sloped portion of a U-shaped curve (Hochwarter et al., 2001).

3.8 Cumulative Risk Factors

3.8.1 Cumulative risk variables. We developed a set of heuristics to identify workstation characteristics and physical conditions that would lead to a higher incidence of low satisfaction, based partly on the regression results reported here and partly on other literature. These are reported elsewhere (Newsham et al., 2003b). Based on these heuristics we developed two new variables to track the cumulative risks in each workstation - that is, the total number of potentially adverse conditions experienced by each respondent. One variable counted only those conditions that will be predicted in the COPE software (RISK_COPE), and the other included all the identified potential risks (RISK_ALL). The criteria used to define these variables are shown in Table 34 together with the descriptive statistics for each variable. Only those cases that had data on all of the variables needed for the cumulative risk calculation were included. Each case received one point for each physical characteristic that met the criterion values. Thus, higher scores indicate that the case had more risk for poor satisfaction.

Both variables were well distributed. There was a slight negative skew to both variables, but both met the criteria for normal distributions that had been previously set. Histograms of both variables are shown in Figure 2. Values for RISK_ALL are of course higher because there were more criteria used to calculate it.

Table 34 also shows the bivariate correlations for the two variables with OES and JobSatis. These dependent variables were used in subsequent analyses of the effects of cumulative risk because the individual domains of satisfaction had been the source of the criteria for their definition. The correlations were expected to be negative (lower risk -- higher satisfaction). Although they are low, the correlations for OES are in the same range as some that had shown interpretable results in the earlier regression analyses.

Figure 2. *Histograms for cumulative risk variables.*

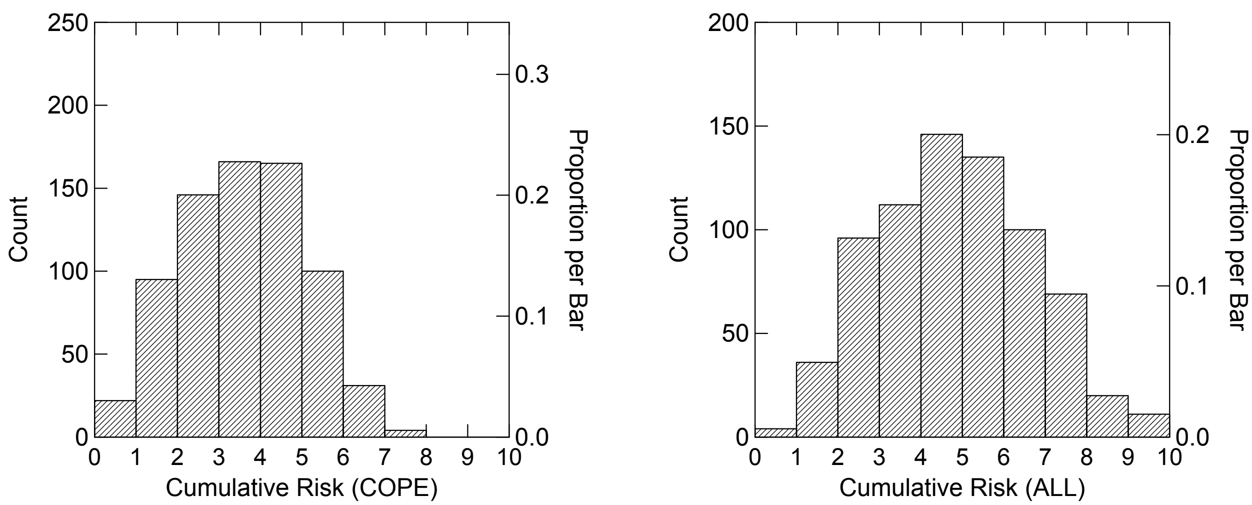

Table 34. *Criteria and descriptive statistics for cumulative risk variables.*

	RISK_COPE	RISK_ALL
SII	>= 0.5	>= 0.5
MINPH_NOOPEN	<= 54 OR>= 66	<= 54 OR>= 66
SQRTAREA	<= 8	<= 8
LNOISEA	<= 44 OR >= 50	<= 44 OR >= 50
DESKILLUM	<= 300	<= 300
VDT_CAT	>= 2	>= 2
WINDOW	= 0	= 0
RTD_H		<= 21.5 OR >= 23.5
AIR_V_H		>= 0.10
FDCO2		>= 650
Minimum	0	0
Maximum	7	10
M	3.10	4.34
SD	1.49	1.88
Median	3	4
N	729	729
OES bivariate correlation (N = 696)	-.04	-.05
JobSatis bivariate correlation (N = 717)	-.01	.00

3.8.2 Predicting overall environmental satisfaction. We conducted hierarchical regression analyses to determine whether or not the cumulative risk scores predicted overall environmental satisfaction and job satisfaction (next section), again controlling for demographic characteristics on Step one. Separate analyses were conducted, first for RISK_COPE and then for RISK_ALL.

Table 35 shows the summary result for RISK_COPE, and Table 36 shows the result for RISK_ALL. Neither regression model was statistically significant at any step, nor was either risk variable a significant predictor of OES.

Table 35. *Summary table for OES regressed on RISK_COPE.*

	β	β
AGE_COMBINED	-.026	-.030
GENDER	.046	.047
ADMIN	.085	.076
MGR	-.010	-.014
PROF	-.053	-.056
RISK_COPE		-.037
R^2 change	.014	.001
Total R^2	.015	.015
Adjusted R^2	.007	.007

Note. N= 689. * p<=.05. ** p<=.01. *** p<=.001.

Table 36. *Summary table for OES regressed on RISK_ALL.*

	β	β
AGE_COMBINED	-.027	-.033
GENDER	.045	.050
ADMIN	.084	.070
MGR	-.010	-.018
PROF	-.054	-.063
RISK_ALL		-.060
R^2 change	.014	.003
Total R^2	.014	.018
Adjusted R^2	.007	.009

Note. N= 688. * *p*<=.05. ***p*<=.01. ****p*<=.001.

3.8.3 Predicting job satisfaction. Tables 37 and 38 show the corresponding analyses for regressions in which JobSatis was the dependent variable. The overall models were statistically significant, but the only statistically significant predictor was age, which again showed a small, negative relationship to job satisfaction, explaining approximately 2% of the variance.

Table 36. *Summary table for JobSatis regressed on RISK_COPE.*

	β	β
AGE_COMBINED	-.124***	-.126***
GENDER	-.006	-.006
ADMIN	-.048	-.052
MGR	.018	.016
PROF	-.022	-.024
RISK_COPE	-.124	-.018
R^2 change	.019*	.000
Total R^2	.019*	.019*
Adjusted R^2	.011*	.010*

Note. N= 696. * *p*<=.05. ** **p*<=.001.

Table 38. *Summary table for JobSatis regressed on RISK_ALL.*

	β	β
AGE_COMBINED	-.124***	-.126***
GENDER	-.007	-.006
ADMIN	-.048	-.053
MGR	.018	.015
PROF	-.023	-.026
RISK_ALL		-.022
R^2 change	.019*	.000
Total R^2	.019*	.019*
Adjusted R^2	.011*	.010*

Note. N= 695. * *p*<=.05. ***p*<=.01. ****p*<=.001.

3.8.4 Discussion: Cumulative risk. Although there was adequate variability in the scores for cumulative risk, neither variable was a statistically significant predictor of either overall environmental satisfaction or job satisfaction. There are several possible explanations. First, it is possible that the relationship is not a linear one. Perhaps low levels of cumulative risks may be tolerated, but a higher level might not. It is also possible that the various risks are not additive in this simple way; rather, each might influence a different outcome, and some might do so in ways than cancel out (e.g., having a window improves satisfaction with lighting but decreases satisfaction with ventilation). Whatever the reason, one implication of this null result is that the risk markers in the COPE software do not add up to an overall score for the satisfaction consequence of any workstation design.

3.9 Ranked Order of Importance of Workstation Features

3.9.1. Frequencies. Seven workstation characteristics were ranked for their relative importance to the individual. In this instance, lower numbers reflect greater importance; thus, a ranking of 1 would indicate the most important element. The responses are summarized in Table 39. Using the mean and median rankings as a guide, the elements sort in the order: Air Quality & Ventilation; Privacy; Noise Levels; Temperature; Lighting; Size; and, Window Access.

Table 39*. Ranked importance of seven workstation features.*

Rank	1	2	3	4	5	6	7	N	*M*	*SD*	Median
Lighting	65	93	138	113	119	115	64	707	4.03	1.78	4.00
Air Quality & Ventilation	163	106	105	109	98	83	43	707	3.42	1.91	3.00
Temperature	80	129	110	98	102	103	85	707	3.94	1.93	4.00
Noise Levels	94	124	97	125	118	84	65	707	3.79	1.86	4.00
Privacy	155	118	103	86	91	97	57	707	3.51	1.99	3.00
Size of Workstation	64	66	101	103	106	132	135	707	4.50	1.93	5.00
Window Access	86	71	53	73	73	93	258	707	4.82	2.20	5.00

3.9.2. Nonparametric analyses. We examined these using the Goodman-Kruskal Gamma non-parametric test to investigate whether the rank assigned to each environmental aspect was influenced by three workstation characteristics: workstation area, partition height, and presence of a window. We also examined the influence of age and job category, because of the effects that these variables showed in some of the regression analyses.

Gamma assesses the relationship between two ordered categorical variables. It may take on values between -1 and +1, and is a proportional reduction of error statistic, meaning that its size tells us the percentage of the cases in which our classification on one variable is improved by knowing the other variable (Wilkinson, Blank, & Gruber, 1996).

As this test can only be conducted using categorical data, we formed categories for the continuous variables, SQRTAREA and MINPH_NOOPEN. Table 40 shows the definitions of the category cutpoints and the number of workstations in each category that resulted. We chose cutpoints that made practical sense: integer numbers of feet for SQRTAREA, and values than seemed to correspond to commonly available systems furniture heights for partition height.

Table 40. *Category definitions for continuous variables.*

SQRTAREA	<= 4	4 - 5	5 - 6	6 - 7	7 - 8	8 -9	9 - 10	10 - 11	11 - 12	12 - 13	>= 13
SQRA_CAT	1	2	3	4	5	6	7	8	9	10	11
#	6		81	110	116	103	111	135	51	54	12

MINPH_NOOPEN	<= 30	30 - 48	48 - 57	57 - 63	63 - 68	68 - 74	>= 74
MINPHCAT	1	2	3	4	5	6	7
#	1	99	150	124	274	127	4

3.9.3 Crosstabulations by workstation area. Table 41 summarizes the results of the crosstabulations of the ranks assigned to each feature, by workstation area. The gamma values in our data show that the relative importance of four features varied by workstation area, all by a small amount (11 to 13%). The relative importance of lighting went up as workstation area increased, but window access declined in importance. The relative importance of air quality and ventilation declined. Noise levels became more important as size increased.

Table 41. *Summary of crosstabulations for feature importance ranks by workstation area.*

Feature	Goodman-Kruskal Gamma
Lighting	.11**
Air Quality & Ventilation	-.12**
Temperature	.02
Noise Levels	.11**
Privacy	.00
Size of Workstation	.02
Window Access	-.13**

Note. ** $p <= .01$

3.9.4 Crosstabulations by partition height Table 42 summarizes the results of the crosstabulations of the ranks assigned to each feature, by partition height. Only two features showed significant relationships, and these were small. The importance of air quality and ventilation declined as partition height increased. The importance of workstation size increased as partition height increased.

Table 42. *Summary of crosstabulations for feature importance ranks by partition height.*

Feature	Goodman-Kruskal Gamma
Lighting	.07
Air Quality & Ventilation	-.10*
Temperature	.02
Noise Levels	.04
Privacy	.00
Size of Workstation	.10*
Window Access	-.12**

Note. * $p <= .05$. ** $p <= .01$

3.9.5 Crosstabulations by windows and daylight Table 43 summarizes the results of the crosstabulations of the ranks assigned to each feature, by the variable NO_DL_WI, which codes for both the presence of a window and access to daylight. These results are intriguing: lighting increases in importance across the change from no daylight, to daylight access, to having a window. Having access to a window, however, declines in importance.

Table 43. *Summary of crosstabulations for feature importance ranks by access to daylight.*

Feature	Goodman-Kruskal Gamma
Lighting	.16**
Air Quality & Ventilation	.01
Temperature	-.01
Noise Levels	.06
Privacy	-.02
Size of Workstation	.05
Window Access	-.23**

Note. ** $p <= .01$

3.9.6 Crosstabulations by age Table 44 summarizes the results of the crosstabulations of the ranks assigned to each feature, by age. Only the importance of air quality and ventilation varied by age, becoming less important for older employees.

Table 44. *Summary of crosstabulations for feature importance ranks by age.*

Feature	Goodman-Kruskal Gamma
Lighting	.07
Air Quality & Ventilation	-.16**
Temperature	.04
Noise Levels	.02
Privacy	.03
Size of Workstation	-.02
Window Access	.02

Note. ** $p <= .01$

3.9.7 Crosstabulations by job category Table 45 summarizes the results of the crosstabulations of the ranks assigned to each feature, by job category. Job category was coded on an assumed gradient of responsibility, where 1 = administrative; 2 = technical; 3 = professional; 4 = managerial. Thus, the results indicate that people in the professional and managerial categories place more importance on temperature, whereas administrative and technical ranks place more importance on noise levels and access to a window. (There was no relationship between job category and having a window or daylight, gamma = .08, n.s.)

Table 45. *Summary of crosstabulations for feature importance ranks by job category.*

Feature	Goodman-Kruskal Gamma
Lighting	.01
Air Quality & Ventilation	.03
Temperature	.20***
Noise Levels	-.11**
Privacy	-.04
Size of Workstation	.03
Window Access	-.11**

Note. ** $p <= .01$. *** $p <= .001$

3.9.8 Discussion: Ranked importance of features. The overall pattern of importance rankings is somewhat surprising: Although size and window access (or daylight) were important predictors of some of the satisfaction outcomes, they did not receive the highest importance rankings. Kupritz (2003a) also found windows to be relatively low-ranking, but in her list “having a large personal office” was the top-ranked item for both younger and older employees.

The crosstabulation of our data show that the relative importance of these features depended on the state of other features. Some of these relationships have parallels in the literature. Boubekri and Haghighat (1993) also found that people without windows rated window access as more important than did people whose cubicles had windows.

The results of the importance rankings seem to suggest that the relative importance of a workstation feature is greater when that feature might be less than optimal. Thus, people with windows rate window access as less important, but lighting, which should include glare control, as more important. This pattern is consistent with the regression analyses for satisfaction with lighting. Professionals experienced lower noise levels than others (Table 8), and rated noise as less important. Those who, traditionally have a lower likelihood of having window access (administrators) place more importance on having it. However, this finding does not hold for all features: lower partition height was associated in the regressions with increased satisfaction with ventilation, but in the rank analysis with more importance for air quality and ventilation.

One relationship that was not present was a connection between age and the importance of privacy. This is consistent with Kupritz (2001) but not with her more recent work (Kupritz, 2003a)*, in which older workers placed more importance on workplace features than would provide more privacy, than did younger workers.

3.10 Open-Ended Comments

At the conclusion of each workstation visit, the research team left a paper questionnaire inviting written comments to three questions, together with a stamped enveloped in which the participant could mail it back to NRC. The response was poor, with 108 completed questionnaires returned from 779 workstations visited (13.9%). The responses to each question were typed verbatim, then categorised. Table 45 shows the top three categories of response to each of the three questions. The number of comments exceeds the number of questionnaires because many people gave more than one response to each question.

The dominant concern of these open-plan office workers is functionality. They want their workstations to have the space and features necessary to the performance of their work. In one area, employees who worked with large building plans complained that there was not enough desk area to unroll and support the entire sheet. Others commented more favourably, “I have the tools (computer, desk) that I need to do my job well.” The quantitative questionnaire did not address this issue directly so there is no easy comparison to the other results.

Privacy appears to follow functionality. Although a large number of favourable responses concerned privacy, a larger number of respondents complained about a lack of privacy, or wanted to make changes in order to improve privacy. This might be considered an extension of functionality: freedom from distractions to enable the work to be done.

On the positive side, and a feature that some would like to change, was availability of a window. Those who mentioned it, wanted a window. No one said they wanted to give up a window.

Finally, air quality and thermal comfort issues merited both complaints and desire for change. Temperature fluctuations over the day from too hot to too cold were among the complaints; others focused on the cold problem. Some complained that the air was stuffy, others that there were smells. We found no favourable comments in this category.

Indeed, there were fewer comments provided in response to “Things I like most” than to the other two questions, suggesting that people were more likely to respond negatively than positively. Perhaps the favourable characteristics are less salient than the features that cause discomfort or annoyance.

Table 45. *Summary of top three categories of open-ended comments.*

THINGS I LIKE MOST		THINGS I LIKE LEAST		THINGS I WOULD CHANGE	
FEATURE	# COMMENTS	FEATURE	# COMMENTS	FEATURE	# COMMENTS
Total	215	Total	247	Total	235
Functionality (enough space, good equipment)	76	Lack of privacy, many distractions, noisy	77	Functionality	71
Window & view	59	Lack of functionality	73	Privacy, distraction, noise	67
Privacy, little distraction	24	Poor IAQ & thermal comfort	41	IAQ, thermal comfort	22
				Window & view	21

* See also Kupritz (2003b) for a discussion of these data as they apply to a variety of routine work activities.

4.0 Conclusions

Taken together, the results of this cross-sectional field study provide modest evidence that the physical environment within the workstation influences its occupant's satisfaction in several ways. The most substantial effects were found for two specific environmental domains: satisfaction with lighting and satisfaction with ventilation, with regressions explaining on the order of 10-14% of the variance in these outcomes. Satisfaction with privacy, overall environmental satisfaction, and job satisfaction effects were smaller in size.

Variables that were not measured in this study probably account for more of the variance in these outcomes. For instance, personality variables such as stimulus screening interact with workstation design characteristics; people who are less able to screen irrelevant stimuli are more affected by enclosure and workstation area than those whose screening skills are high (Oldham et al., 1991; Oldham & Fried, 1987). These relationships may be complex: Block and Stokes (1989) observed that sex, introversion/extroversion, and task type interacted with office type (open or enclosed) to influence task performance. Job complexity, which is not fully accounted for by the gross categorization of job type that we controlled for, also interacts with workstation characteristics and physical conditions such as noise to influence job satisfaction (Leather et al., 2003; Melamed et al., 2001; Oldham et al., 1991). Adverse environmental conditions are tolerable by those with less complex jobs, but not for those with complex or demanding jobs. Our investigation, with its strict focus on varieties of satisfaction and limits to the questionnaire length, was not able to incorporate measurements of these variables.

Another important finding is that although conditions occur across a wide range, satisfaction levels - particularly for satisfaction with lighting and job satisfaction - are relatively high. The physical conditions, too, compare well against recommended practice. There were few cases of ventilation or thermal conditions outside the recommended ranges; similarly, noise levels were not particularly high. Speech intelligibility levels, when calculated with the "normal speech" level, were poor (mean SII=.51), but there is evidence that people in open-plan offices speak more quietly (Warnock & Chu, 2002). A recalculation with this lower speech level resulted in an average SII = .20 (J. Bradley, personal communication, July 22, 2003), which is the target value adopted by acousticians (American National Standards Institute, 1997). Although there were workstations with potentially problematic reflected images in the VDT screen, the overall lighting levels were well within recommended practice. Given the low frequency of very poor conditions by commonly accepted standards, the small percentage of variance explained is not surprising.

We found some evidence that the effects on overall environmental satisfaction and job satisfaction are indirect. That is, workstation physical characteristics and physical conditions have larger direct effects on the three subscales (satisfaction with privacy, satisfaction with ventilation, and satisfaction with lighting), than on overall environmental satisfaction or job satisfaction. This is consistent with the satisfaction model previously developed (Charles et al., 2003), and with previous theory in environmental satisfaction (Marans & Spreckelmeyer, 1982; Marans & Yan, 1989). The indirect nature of the relationship probably accounts for the finding that the cumulative risk factors did not predict either overall environmental satisfaction or job satisfaction. Another contributing element is the fact that some of the risk factors have two faces: For instance, having a window is a good thing for satisfaction with lighting, but a bad thing for satisfaction with ventilation.

Nonetheless, the results provide guidance for improving satisfaction with open-plan offices that designers may use even when such details about occupants are not known. It appears from these regressions that the single most influential design change that can improve satisfaction is to provide a window, or at least access to daylight within 5 m (15 ft) of the workstation. However, one must also simultaneously provide a means of glare control and take steps to moderate the thermal effects of the window - so that it is neither too hot when there is direct sun, nor too cold in winter. Another positive step for employees is to increase workstation size, which was positively related to satisfaction with privacy, satisfaction with lighting, and satisfaction with ventilation in some (although not all) analyses.

It is counterintuitive that lower partition heights were associated with higher overall environmental satisfaction and higher job satisfaction. One possible explanation is the greater daylight penetration that lower partitions afford. The relationship disappeared when lighting conditions were controlled, and did not occur at all for central workstations. The separate model for peripheral workstations showed greater environmental satisfaction for larger workstations, no relationship to partition height, and greater environmental satisfaction with no window (but access to daylight). The importance of daylight, as opposed to a window with a view, merits further study.

As regards ventilation, the results suggest that the presence of a supply diffuser for each workstation can improve satisfaction. Moreover, greater research attention should be paid to the concentrations of various pollutants, as it appears that occupants may be more sensitive to low concentrations than was previously thought. This might explain the high ranking for importance given to indoor air quality ventilation issues.

The open-ended responses provided a reminder of the importance of the fit between workstation design and task demands. Functionality was the element most often mentioned in these comments, both as an element that worked and as an element that individuals would want to change. The COPE field study was not designed to identify the specific space and furnishings needs of each occupation, and therefore no recommendations of this kind are possible. Privacy, which was ranked as important both in the open-ended responses and in the importance rankings, might be considered an extension of functionality. Further discussion of both of these issues is available in the COPE report by Marquardt, Veitch, and Charles (2002).

This field study is the only one, to our knowledge, to combine such a detailed set of physical measurements of workstation conditions with psychometrically valid measurements of satisfaction in all of its aspects. The next steps for research in this area should include a wider range of variables relating to occupants, their work, and their organizations, to enable a finer-grained analysis and prescriptions for workplace design that are tailored to individuals and their specific requirements.

5.0 References

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Acknowledgements

This investigation forms part of the Field Study sub-task for the NRC/IRC project Cost-effective Open-Plan Environments (COPE) (NRCC Project # B3205), supported by Public Works and Government Services Canada, the Building Technology Transfer Forum, Ontario Realty Corp., USG Corp., British Columbia Buildings Corp., Natural Resources Canada, and Steelcase, Inc. COPE is a multi-disciplinary project directed towards the development of a decision tool for the design, furnishing, and operation of open-plan offices that are satisfactory to occupants, energy-efficient, and cost-effective. Information about COPE is available at http://irc.nrc-cnrc.gc.ca/ie/cope/.

The authors are grateful to the following individuals: Chantal Arsenault, John Bradley, Marcel Brouzes, Natalie Brunette, Raymond Demers, Ryan Eccles, Tim Estabrooks, Brian Fitzpatrick, Ralston Jaekel, Judy Jennings, Roger Marchand, Emily Nichols, and Scott Norcross (data collection); Louise Legault (research design advice); Kelly Farley (data analysis); Gordon Bazana and Cara Duval (data management). We also thank the management and employees in the nine buildings for their participation.

Appendix A: Derived Thermal Indices Regressions

Derived Thermal Indices

There exist derived indices for thermal comfort (predicted mean vote, PMV, and predicted percentage dissatisfied, PPD) (Fanger, 1982) and discomfort caused by draught (Fanger, Melikov, Hanzawa, & Ring, 1988). Further details of these indices can be found in Charles (2003). We calculated these using the standard formulae, using common assumptions for the values that we had not measured.

PMV and PPD were calculated using a computer program provided in ISO Standard 7730 (International Organization for Standardization (ISO), 1984). For the variables that were not measured in the COPE field study, the assumptions shown in Table XXX were used. The PMV index provides a thermal comfort score ranging from –3 (cold) to +3 (hot). As a variable in this form would be difficult to interpret in the regression analyses, we used PMV's related index, the predicted percentage dissatisfied (PPD) for these regressions.

Table A1. *Assumptions for PMV and PPD calculations.*

Variable	Units	Source
Metabolism	W/m^2	Standard value for office work: 70 (equivalent to 1.2 met) (ISO 1984; ASHRAE, 1992)
External Work	W/m^2	Standard value for office work: 0 (ISO, 1984; ASHRAE, 1992)
Clothing	$m^2.^oC$ /W	Standard value by season: spring 0.11, summer 0.08, fall 0.11, winter 0.16 (equivalent to clo values of 0.7, 0.5, 0.7, 1.0 respectively) (ISO, 1984)

The draught index was calculated using the formula provided in ASHRAE Standard-55 (American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE), 1992), using an assumed turbulence intensity of 35% (as recommended in this Standard). The draught index was calculated at both the head and ankle heights, these being the areas most susceptible to draught discomfort (American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE), 1992). However, to be consistent with the previous regression analyses using the raw variables, we used only the draught index calculated at head height (DRAUGHT_H) as a regression predictor.

We then repeated the analyses that we had earlier conducted using the raw measurements of ventilation conditions, using these derived indices in their places.

Predicting Satisfaction with Ventilation

Table A2 shows the results for the regression using derived thermal indices in place of the raw measurements (shown in Table 19). The percentage of variance explained is slightly lower (12% instead of 14%). Whereas both air movement and temperature were significant predictors in the raw measurements model, only draught is significant here. The magnitude and direction of the other effects are consistent with the raw measurements model.

Table A2. *Summary table for Sat_Vent regressed on workstation characteristics and derived ventilation indices.*

	β	β	β	β	β
AGE_COMBINED	-.054	-.015	-.020	-.020	-.010
GENDER	.184***	.196***	.208***	.207***	.216***
ADMIN	-.058	.000	-.004	-.005	-.005
MGR	.008	.028	.020	.028	.014
PROF	.001	.062	.053	.055	.059
SQRTAREA		-.040	-.058	-.080	-.084
MINPH_NOOPEN		-.157***	-.170***	-.185***	-.174***
PANELS_CAT		-.022	-.013	-.009	-.013
WINDOW		-.095*	-.105**	-.110**	-.111**
PPD			.079*	.086*	.060
DRAUGHT_H			-.086*	-.092*	-.091*
DL_OUT				-.076	-.082*
FDCO2					-.116**
POLLUT					.000
R^2 change	.048***	.050***	.010*	.005	.012**
Total R^2	.048***	.098***	.109***	.114***	.126***
Adjusted R^2	.041***	.087***	.095***	.098***	.108***

Note. N= 713. * p<=.05. **p<=.01. ***p<=.001.

Predicting Overall Environmental Satisfaction

Overall environmental satisfaction results are shown in Table A3. the comparable analysis for the raw measurements is shown in Table 26. The percentage of variance explained in the two models was the same, but the significant predictors are not the same. Although neither temperature nor humidity were statistically significant predictors in the raw measurements model, PPD is significant here (Table A3). As expected, conditions leading to higher PPD predictions are associated with higher OES. This is a very small effect, with PPD and draught together contributing only 0.7% to the explained variance.

Table A3. *Summary table for OES regressed on workstation characteristics and derived ventilation indices.*

	β	β	β	β	β
AGE_COMBINED	-.026	-.029	-.032	-.031	-.027
GENDER	.043	.042	.049	.047	.050
ADMIN	.065	.071	.063	.063	.064
MGR	-.041	-.045	-.052	-.038	-.043
PROF	-.090	-.078	-.086	-.082	-.080
SQRTAREA		.097	.081	.043	.044
MINPH_NOOPEN		-.131*	-.137**	-.159**	-.158**
PANELS_CAT		-.034	-.025	-.020	-.021
WINDOW		-.024	-.033	-.042	-.044
PPD			.084*	.096*	.089*
DRAUGHT_H			-.047	-.058	-.058
DL_OUT				-.126**	-.127**
FDCO2					-.040
POLLUT					-.006
R^2 change	.019*	.011	.007	.013**	.002
Total R^2	.019*	.030*	.037**	.050***	.051***
Adjusted R^2	.012*	.017*	.022**	.033***	.032***

Note. N= 689. * p<=.05. **p<=.01. ***p<=.001.

Predicting Job Satisfaction

Results for the regressions involving job satisfaction are shown in Table A4 for the derived indices, and Table 33 for the raw measurements. They explain similar amounts of variance (6.7 % and 6.9%), but in the raw measurements model both carbon dioxide and other pollutants were statistically significant predictors. The other predictors are the same for both models.

Table A4. *Summary table for JobSatis regressed on workstation characteristics and derived ventilation indices.*

	β	β	β	β	β
AGE_COMBINED	-.135***	-.120**	-.120**	-.120**	-.107**
GENDER	.001	.003	.005	.004	.013
ADMIN	-.052	-.012	-.009	-.010	-.006
MGR	.026	.029	.030	.036	.015
PROF	-.022	.022	.022	.024	.030
SQRTAREA		-.057	-.053	-.069	-.055
MINPH_NOOPEN		-.092	-.095	-.107*	-.113*
PANELS_CAT		-.040	-.042	-.040	-.037
WINDOW		.050	.053	.049	.035
PPD			-.030	-.024	-.029
DRAUGHT_H			-.010	-.015	-.015
DL_OUT				-.058	-.059
FDCO2					-.121**
POLLUT					-.079
R^2 change	.023**	.022**	.001	.003	.021***
Total R^2	.023**	.044***	.045***	.048***	.069***
Adjusted R^2	.016**	.032***	.030***	.031***	.050***

Note. N= 695. * $p<=.05$. ** $p<=.01$. *** $p<=.001$.

Summary

The derived indices rely on several assumptions for their calculation from field data such as this, which one would expect would reduce their reliability. Overall, the results for the analyses with the raw data seem to be more useful, given that the raw measurements allow more precise statements about the causes of effects and that more predictors reached statistical significance in those models.