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Publisher's version / Version de l'éditeur:
https://doi.org/10.1111/j.1600-0668.2008.00525.x
Indoor Air, 18, August 4, pp. 271-282, 2008-08-01

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NRCC-48668

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August 2008

A version of this document is published in / Une version de ce document se trouve dans:
Indoor Air, 18, (4), August, pp. 271-282, DOI: 10.1111/j.1600-0668.2008.00525.x

RISK FACTORS FOR DISSATISFACTION WITH THE INDOOR ENVIRONMENT IN OPEN-PLAN OFFICES: AN ANALYSIS OF COPE FIELD STUDY DATA

ABSTRACT

We applied binary logistic regression techniques to data collected from 779 participants in a field study of open-plan ("cubicle") offices conducted in nine buildings. Independent variables were physical conditions in the workplace, and dependent variables were derived from occupant satisfaction measures; personal characteristics were included as covariates. There was a significantly higher risk of dissatisfaction with privacy & acoustics (defined as being below the 20th percentile as opposed to being above the 80th percentile) associated with being in a small workstation, or being seated next to a window. A higher risk of dissatisfaction with ventilation was associated with being seated next to a window, temperatures substantially higher than the average neutral temperature, and a carbon dioxide concentration greater than 650 ppm. A higher risk of dissatisfaction with lighting was associated with panel heights greater than 66 inches (1.7 m), high reflected glare on computer screens, desktop illuminances outside 300-500 lux, desktop illuminance uniformity (min/max ratio) less than 0.5, and being in a workstation distant from a window.

Keywords
Lighting, Ventilation, Acoustics, Privacy, Thermal Comfort, Windows

Practical Implications
We have demonstrated statistically significant relationships between indoor environment conditions in office spaces and environmental dissatisfaction risk. Although generally supported by prior research, not all of these risk factors are reflected in existing recommended practice documents for office design. Consideration of these findings in future revisions of such documents may be warranted.

INTRODUCTION

A link between the indoor environment experienced by office workers and the productivity of their organization has long been assumed by researchers and building occupants alike. However, objective evidence has proven elusive. Much early research focused on the direct link from environmental conditions to the task performance of individuals. However laboratory studies have not shown consistent relationships over the range of environmental conditions commonly experienced in offices in developed countries, particularly the deep-plan, sealed and mechanically tempered office buildings common in North America [Fisk & Rosenfeld, 1996; Wargocki et al., 2002; Veitch & Newsham, 1998]. Further, it has become increasingly accepted that performance on the kind of routine, repetitive tasks commonly studied in laboratory experiments is of little relevance to the productivity of "knowledge worker" organizations, which form the bulk of office tenants today. For knowledge workers, job satisfaction is likely a far more important predictor of organizational success – to quote Roznowski & Hulin [1992]: "… job satisfaction [scores] are the most useful information organizational psychologists or organizational managers could have [for] predicting a variety of behaviours of organizational members".

In this regard, the results of past research are more compelling. Although an entire model from environmental satisfaction to organizational productivity has yet to be established on a single data set, elements of the model have been verified in real workplaces. For example, Charles et al. [2003] demonstrated a positive link between environmental satisfaction and job satisfaction, and Zweers et al. [1990] found that lower levels of indoor climate complaints were associated with higher job satisfaction. In turn, many recent studies have linked job satisfaction to important aspects of organizational productivity. Individuals with lower job satisfaction have been found to have lower levels of organizational commitment, and a higher intent to leave their employment (turnover) [Carlopio, 1996; Lambert et al., 2001], and Allen et al. [2005] found a significant correlation between lower job satisfaction and actual turnover. Some observers suggest that the cost of replacing an employee who voluntarily leaves an organization can be around two times their annual salary [Gucer et al., 2003]. Judge et al. [2001] also found a significant positive correlation between individual job satisfaction and manager-assessed job performance, a correlation that was stronger among high-complexity jobs. Higher levels of job satisfaction were also significantly associated with lower levels of sick building syndrome (SBS) symptoms [Brasche et al. 2001], and lower levels of self-reported sick leave [Preller et al. 1990]. Other researchers have looked at job satisfaction averaged across business units, and then studied business unit behaviour (these studies included many types of work, including, but not limited to, office work and service industry work). Higher average job satisfaction in a business unit was correlated with higher customer loyalty, lower employee turnover, better safety records, and higher profitability [Harter et al., 2002], and was associated with higher returns on assets and earnings per share [Schneider et al., 2003].

Taking these findings together suggests that improving environmental satisfaction is good for organizational productivity. The key question for those who design and operate office buildings is then: what aspects of the physical environment predict environmental satisfaction? There are many studies addressing this question, and recommendations have been developed with some regard to the results of these studies [e.g. ASHRAE, 2004; IESNA, 2000]. However, the vast majority of such studies were conducted in controlled laboratories and climate chambers, and focused almost exclusively on single aspects of environmental satisfaction. Field studies of thermal comfort criteria [de Dear & Brager, 1998], recommendations related to outdoor ventilation rates [Charles & Veitch, 2002] and to SBS issues [e.g. Chao et al., 2003; Preller et al., 1990; Mizoue et al., 2004; Ooi et al., 1998] have been conducted, but field studies related to lighting [one example is Collins et al. 1990] and acoustics, are rarer [Navai & Veitch, 2003]. Rarer still are field studies that tackle many aspects of environmental satisfaction simultaneously.

In this paper we analyze data from a large field study designed to examine relationships between physical variables and environmental satisfaction in several domains. We were particularly interested in validating specific existing recommended criteria for office environments with respect to environmental satisfaction (or avoiding environmental dissatisfaction), and possibly deriving new criteria.

METHODS

Setting and Participants

This was a cross-sectional study, data were collected from 779 workstations and their occupants in nine buildings between Spring 2000 and Spring 2002. Five of the buildings were occupied by public sector Canadian organizations, and four were occupied by private sector organizations in either Canada or the United States. Table 1 summarizes the demographic characteristics of the participants.

Physical Measurements

Measurements of the physical environment were made in every workstation. The physical measurements were taken using a cart-and-chair system developed for this study (see Figure 1). During a workstation visit, the occupant's regular chair was removed, and replaced with the measurement chair. The measurement chair carried sensors to record sound level, temperature and air movement, relative humidity, concentrations of various air pollutants, and illuminance. A set of six illuminance sensors set into the faces of a black cube was at the approximate location of the head of a seated occupant. In addition, two illuminance meters on cables were used to measure horizontal desktop illuminance at four fixed locations on the work surface. The investigator manually recorded the size of the workstation, height of panels surrounding the workstation (these were always higher than the desktop, making it straightforward to define an individual workstation area in an open-plan setting), number of enclosed sides of the workstation, presence of a window, luminaire type, presence of a task light, location of the nearest air supply, and the presence of nearby high-noise areas. The investigator also took photographs of the workstation from its entrance and a close-up of the computer screen (VDT monitor). Physical measurements at each workstation were collected over a period of about 10 minutes. Table 2 describes the physical variables used in the analyses in this paper.

Additional acoustic and illuminance measurements were taken at night, with no occupants and no daylight. In particular, the nighttime acoustics measurements were used in the calculation of the Speech Intelligibility Index (SII in Table 2). A microphone array was placed in the workstation of interest, and detected noise generated by a loudspeaker at the centre of a neighbouring workstation. The choice of which neighbouring workstation was based on a judgement of which one presented the greatest potential speech privacy problem. This measurement defined the basic sound propagation characteristics. The SII calculation for daytime conditions also requires a speech and background noise level. Bradley [2003b] showed that the "normal" speech level commonly assumed in SII calculations is likely too high for open-plan offices. He suggested a lower level, termed IOSL, which is approximately 7 dBA lower than the "normal" level. The background noise level measurement was derived from the daytime measurement using the cart-and-chair system. The goal was to get a 20-second measurement in each workstation without intelligible speech sounds (LNOISE in Table 2). Measurements were repeated 3 times, or until a measurement without speech was captured, whichever occurred sooner.

Satisfaction Questionnaire

Occupants completed a 27-item questionnaire in an adjacent workstation while the physical measurements were conducted in their own workstations. The questionnaire covered satisfaction with individual features of the workstation, the environment overall and the job, asked participants to rank-order the importance of seven physical features, and to provide basic demographic characteristics. A mail-back questionnaire was provided to allow for longer comments.

Eighteen questions asked for ratings of satisfaction with specific physical environmental features; ratings were on a 1 – 7 scale, from Very Unsatisfactory to Very Satisfactory. Exploratory and confirmatory factor analysis established that these eighteen items formed three distinct scales: satisfaction with privacy & acoustics, satisfaction with ventilation, and satisfaction with lighting [Charles et al., 2003; Veitch et al., 2002a]. Values on these composite scales were calculated as the mean of the ratings on the individual items comprising the scale. Table 3 shows the attribution of individual questionnaire items to scales.

Analysis Method

We initially conducted a hierarchical linear regression analysis on these data [Veitch et al., 2003], which was successful in identifying aspects of the indoor environment that affect environmental satisfaction, and the direction of the effects. In the current analysis however, we were interested in validating and deriving specific recommended criteria for office environments with respect to environmental satisfaction. The statistical technique we chose for this was binary logistic regression (BLR). SBS research has often used logistic regression when the outcome is health symptoms [e.g. Chao et al., 2003; Preller et al., 1990; Mizoue et al., 2004; Ooi et al., 1998], and logistic regression has also been used to relate health issues to voluntary turnover [Gucer et al., 2003]. In the context of our interest in examining recommended criteria, BLR presents several potential advantages. First, BLR does not require that the data for each variable of interest be normally distributed, or that data for all combinations of variables be present in the sample, as required by analysis of variance (ANOVA). Second, linear regression defines significant trends, but deriving criteria for practice from these trends is not always obvious. BLR requires all independent and dependent variables to be categorical, and categorizing the independent variables automatically defines potential criteria if the differences between the categories prove to be significant (the trade-off is that categorizing loses some information). Third, the results of BLR are expressed as odds ratios: the relative chance or risk of something being true through membership in one category of the independent variable rather than membership in another. Odds ratios are arguably more accessible to non-experts than other statistical measures. Fourth, in the context of seeking a larger model of relationships of how people respond to buildings, it seems helpful to express the results of satisfaction studies in a similar way to the results of SBS studies.

Categorization of Variables

Binary Logistic Regression requires that all variables used in the analysis are categorical. Table 4 describes the categorization of the variables used, with more explanation below. The outcomes of interest were based on the three composite satisfaction variables. In this paper, we are particularly interested in conditions that cause dissatisfaction, which should therefore be avoided by the practitioner. Specifically, we chose to focus on extreme dissatisfaction, of the kind that might lead to a specific complaint or avoidance action. There is no clear guidance on what "extreme" is in this context, and the choice is somewhat arbitrary. However, thermal comfort standards commonly specify thermal conditions resulting in no more that 20% of people being dissatisfied [ASHRAE, 2004]. Further, in a building-level analysis, Wang et al. [2005] found a significant positive correlation between dissatisfaction with temperature and hot/cold complaints recorded by building maintenance personnel. By (loose) analogy, in this paper, for each satisfaction measure, we looked at the group in the bottom 20% (at or below the 20^{th} percentile) as the "at risk" group. We compared them to the group that is in the top 20% (at or above the 80^{th} percentile). Although this reduces the sample size to around 40% of the original sample, it serves to increase the discrimination between groups. Chi-squared tests revealed no substantial differences on demographic characteristics between the 40% sample included in the analysis, and the 60% excluded, indicating no loss of generalizability in the interpretation of results. As a further check, we ran our analyses using a median split to decide satisfaction group membership instead, and got very similar results in terms of which predictor variables were significant. However, the variance explained by these models was much lower, because of the reduced discrimination between dependent variable groups. Therefore, the results of our analyses will indicate which conditions are more likely to prevail for people in the bottom 20%, compared to those in the top 20%.

The independent predictor variables were drawn from the measurements made at the individual workstations. The categories for these predictors were based on criteria from existing standards, suggestions from prior research, or, in the absence of standards or convincing prior research, round numbers with face validity that gave groups of not too dissimilar size. Predictor variables were divided into two or three categories.

A graphical analysis [Newsham et al., 2004] suggested that a workstation size (square root of area) of between 7 and 8 ft (2.1-2.4 m) might represent a lower criterion with respect to satisfaction, whereas 10 ft (3 m) was a typical standard size for much of our sample. Splitting the sample this way also produced three groups of approximately equal size. For panel height, 54 inches (1.4 m) is the approximate height at which two seated people will not see each other directly, and therefore might be important for privacy, whereas 66 inches (1.7 m) was a typical standard size for much of our sample. Splitting the sample this way also produced three groups of approximately equal size.

A Speech Intelligibility Index (SII) of 0.2 is recommended for a reasonable level of speech privacy [Bradley, 2003a]. Veitch et al. [2002b] supported this value with laboratory research, and Bradley and Gover [2004] showed in controlled listening tests that 50% of people can understand around 85% of the words from an adjacent office at an SII of 0.2. An SII of 0.35 was chosen as the other criterion to produce three groups of approximately equal size. For background noise Veitch et al. [2002b] and Bradley & Gover [2004] recommend a level high enough to provide some masking of distracting speech sounds, but not so loud that it becomes annoying in itself; they suggested 45 dBA, with 48 dBA considered too high. Therefore we chose ± 3dBA around 45 dBA as a desirable range, and values above and below this for the other groups.

Recommended practice for desktop illuminance in office spaces with computer screens is typically 300 to 500 lux [e.g. IESNA, 2000], and so we chose these as our lower and upper criteria. Saunders [1969] recommended a minimum-to-maximum illuminance ratio (min/max) of 0.7 between desks. In later work looking at illuminance ratios across an individual desk, Slater and Boyce [1990] suggested 0.7 might be too restrictive, and that 0.5 might be more appropriate. We therefore chose 0.7 and 0.5 as our upper and lower criteria. There are no well-established criteria for horizontal-to-vertical illuminance ratio. Therefore we chose criteria that yielded groups of approximately equal size.

ASHRAE [2004] recommends that air velocity should be lower than 0.2 ms^{-1} to avoid risk of draught. However, an earlier graphical analysis [Newsham et al., 2004] suggested that 0.1 ms^{-1} might represent a lower criterion with respect to satisfaction. The measured velocities in our sample were generally low, and so a criterion of 0.1 ms^{-1} yielded groups more equal in size than a higher criterion. Fanger's thermal comfort equation is the foundation of the most widely used thermal comfort standards [ASHRAE, 2004; ISO, 1994]. Putting in the mean observed values for relative humidity (30%) and air velocity (0.09 ms^{-1}), assuming a typical sedentary activity (1.2 met), and a light office clothing ensemble (0.8 clo insulation), and the common assumption that radiant temperature equals air temperature, Fanger's equation yields an average neutral temperature for our sample of 23.2 ^oC. For category criteria, we took temperatures $\pm$ 0.5 ^oC around this neutral temperature. The measured relative humidities in our sample were generally low; ASHRAE [2004] recommends a lower limit for humidity, to avoid drying of the mucus membranes and static electric shocks, of 30%. Therefore we used 30% as our single criterion in a two-category variable.

Carbon dioxide concentration is a common surrogate for indoor pollutants and ventilation effectiveness. ASHRAE [2001] recommends carbon dioxide concentrations no higher than 1000 ppm, but Seppanen et al. [1999] noted several studies suggesting decreases in SBS symptoms below 800 ppm. An earlier graphical analysis [Newsham et al., 2004] suggested that 650 ppm might represent a suitable criterion with respect to satisfaction. Apte et al. [2000] found significantly increased odds ratios for some SBS symptoms with CO_2 levels 250 ppm above outdoor levels, or about 650 ppm.

Personal attributes of the participants were included in the models as covariates. We included job category, gender, and age category.

We developed binary logistic regression (BLR) models for each of the satisfaction outcomes separately. In each model, all covariates and relevant predictor variables were entered together in a multivariate model. When interpreting the results, the effect of each significant predictor variable is discussed as a main effect. Many of the predictor variables are intercorrelated, and there is therefore the potential for significant interactions. Interactions can be entered into the models explicitly. It would be impractical to enter all possible interactions, however, given the number of predictors of potential interest in our data. Further, we do not have the data to meaningfully support all interactions. For example, WS and PH are correlated: smaller workstations tend to have lower panels, but small workstations with high panels and large workstations with low panels were not present in our data set (and are uncommon in practice). We did, in fact, experiment with adding some specific interactions into the models, but there was no substantial improvement in model performance or interpretability.

We recommend that specific interactions could be investigated in future, dedicated studies.

RESULTS

Satisfaction with Privacy & Acoustics

Table 5 shows the BLR results for SAT_PRIV. We will first describe the structure of Table 5 in detail; the same structure applies to Tables 6-9. The first row of the table shows the dependent satisfaction variable and the size of the sample that were in the "extreme" satisfaction categories, Bottom and Top 20%; sample sizes are shown in all tables separately because the categorization process created slightly different sample sizes for each analysis. On the second row are statistics referring to the overall model: χ^2 indicating if the model was significant, and the Nagelkerke *pseudo* R^2, which is the closest approximation to the traditional percentage of variance explained statistic in linear regression models. On rows four to six are the covariates and their associated odds ratios (OR). On the subsequent rows are the individual physical environment predictor variables and sample sizes, and the associated OR for each category of the predictor. The OR indicates the relative likelihood that a participant experiencing that particular physical condition was in the Bottom 20% satisfaction group, rather than the Top 20% group, compared to participants experiencing the reference physical condition (the 95% confidence limits for the OR are also shown). Values of OR greater than 1 mean participants experiencing that physical condition would be more likely to be in the very dissatisfied group, whereas values of OR less than 1 mean participants would be less likely to be in very dissatisfied group.

Table 5 shows a significant effect of workstation size. Specifically, participants in workstations with WS <7 were more than 10 times more likely (OR=10.46) to be in the Bottom 20% than the Top 20% compared to those in workstations where WS $\geq$10. . Window distance was also a significant predictor: compared to people with windows in the workstation, people more than 15 ft (5 m) from a window were about half as likely (OR=0.53) to be in the very dissatisfied group. This can be stated as people with windows were about twice as likely to be in the very dissatisfied group compared to those distant from a window. Similarly, people with windows were about five times more likely to be in the very dissatisfied group compared to those within 15 ft (5 m) of a window, but without a window of their own (OR=0.18).

All of the covariates were significant. The odds ratios for each covariate are not separated by category, but do indicate the trend as the category "increases". Table 5 shows that people in higher job categories were more likely to be in the very dissatisfied group. Gender has only two categories, therefore we can conclude that men are half as likely (OR=0.50) to be in very dissatisfied group than women. Table 5 also shows that older people were more likely to be in the dissatisfied group than younger people.

Satisfaction with Ventilation
Table 6 shows the results of the BLR with respect to SAT_VENT. Table 6 shows a significant effect of window distance: people with windows were about twice as likely to be in the very dissatisfied group compared to those distant from a window (OR=0.47), and about three times as likely to be in the very dissatisfied group compared to those within 15 ft (5 m) of a window, but without a window of their own (OR=0.33). Temperature was also significant: people experiencing a temperature within 0.5^{o}C of the average calculated neutral temperature were three times less likely (OR=0.32) to be in the very dissatisfied group, compared to people experiencing a higher temperature. Carbon dioxide concentration was significant: people experiencing $CO_2 < 650$ ppm were around three times less likely (OR=0.37) to be in the very dissatisfied group.

The gender covariate was significant: women were four times more likely to be in the very dissatisfied group than men (OR=0.25).

Satisfaction with Lighting
Table 7 shows the results of the BLR with respect to SAT_LIGH. Table 7 shows a significant effect of panel height: people with PH < 54 inches (1.4 m) were about three times less likely (OR=0.31) to be in the very dissatisfied group compared to those with PH > 66 inches (1.7 m). Glare on computer screens was also significant: compared to people with high glare on computer screens, people with low glare were about three times less likely (OR=0.37) to be in the very dissatisfied group, and people with medium glare were about two times less likely (OR=0.45) to be in the very dissatisfied group. Desktop illuminance was also significant: people with illuminance 300 – 500 lux were about half as likely (OR=0.51) to be in the very dissatisfied group compared to people with higher illuminance. Illuminance uniformity was significant too: people in the middle category were about three times less likely (OR=0.35) to be in the very dissatisfied group compared to people with the poorest uniformity. . Finally, window distance was a strong predictor in the model: compared to people with a window in their workstation, people more than 15 ft (5 m) from a window were seven times as likely (OR=6.99) to be in the very dissatisfied group, and people within 15 ft (5 m) of a window but without a window in their workstation were more than three times as likely (OR=3.36) to be in the very dissatisfied group.

Satisfaction with lighting is clearly very strongly affected by window proximity, an effect that might mask other effects of interest. Therefore we split the sample into two groups, central workstations (WIND = no) and peripheral workstations (WIND = dl or wi) and performed a separate binary logistic regression on each of these groups, shown in Table 8 and Table 9, respectively.

Table 8 shows the same uniformity effect as for the whole sample, albeit with a lower odds ratio (OR=0.20). In this analysis the job category covariate was also significant, indicating that people in the higher job categories were more likely to be in the very dissatisfied group.

Table 9 shows that for illuminance uniformity the benefit of the middle uniformity category persisted in peripheral offices (OR=0.42). The significant effect of computer screen glare that was present in the whole sample was also observed (OR=0.31 for low glare), as was the effect of desktop illuminance (OR=0.45 for 300 – 500 lx). Workstation size was significant for this group: people in workstations where WS < 7 were more than four times as likely (OR=4.53) to be in the very dissatisfied group, compared to those where WS ≥ 10. Horizontal-to-vertical illuminance ratio was also significant: people experiencing the lower ratios were about four times less likely (OR=0.21 and 0.24) to be in the very dissatisfied group, compared to those in the highest ratio category. .

DISCUSSION

The use of the binary logistic regression method on these data generated a number of significant results that both support and extend existing recommended criteria for satisfactory indoor environment conditions. Explanations for these results, and links to other research, are discussed in the following sections.

Satisfaction with Privacy & Acoustics

The workstation size effect in Table 5 is consistent with Duval [2002], which associated lower spatial density with increased environmental satisfaction, and has face validity: we would expect that the closer people are to each other the less satisfied they will be with privacy. Windows are generally perceived as desirable elements in the workplace, but Table 5 shows a negative effect on satisfaction with privacy & acoustics. This may be because of visual privacy concerns related to view from outside the building. It may also be explained by acoustic issues: windows provide a hard surface for reflecting sound between workstations, which is exacerbated by the fact that there is often a large gap between the window and the furniture panel separating two workstations. It was somewhat surprising that panel height was not significant, despite the fact that lower panels seriously compromise visual and acoustic privacy. Kupritz [2003] found no effect of panel height, but noted that this contradicted earlier findings. In our study the lack of effect might be because workstation size and panel height were intercorrelated, and smaller workstations, which tended to have lower panels, were associated with dissatisfaction. SII was not a significant predictor either, despite laboratory studies that show an effect [Veitch et al., 2002b]. This may be because of the assumptions made in calculating SII from field measurements.

The effects of covariates followed expectations. One could argue that an increase in job category (going from left to right in Table 4) represents an increase in seniority or job demands, which would lead to a greater demand for privacy. It is common that women report significantly higher occurrences of sick building syndrome symptoms (SBS) [Zweers et al., 1990; Ooi et al., 1998; Brasche et al., 2001], and our finding on satisfaction with privacy & acoustics may be analogous to this. However, note that Zweers et al. [1990] found that noise was the one area of indoor environment complaint where women complained significantly less than men. There are certainly many suggestions in the popular media that younger workers have different expectations for privacy. Kupritz [2003] found that older workers placed more importance on workplace features that would provide more privacy, than did younger workers, and Zweers et al. [1990] found the odds ratio for noise complaints to be significantly lower for people under 30 years old, compared to those over 30. The older groups in any workplace would tend to have more seniority and more work demands, and hence likely a greater desire for privacy.

Satisfaction with Ventilation
The negative effect of windows on satisfaction with ventilation might seem surprising at first. However, the explanation might lie in the fact that SAT_VENT included thermal comfort, and people near windows tend to experience greater extremes of temperature. Note, as is common in North America, only one building in our sample had windows that could be opened, so the likely benefits of windows on ventilation in this regard were not generally available. The effect of temperature was consistent with accepted thermal comfort standards. Burge [2004] also demonstrated that higher indoor air temperatures (in this case the criterion was 23 ^{o}C) in air-conditioned buildings in northern Europe were consistently associated with higher SBS symptoms. Note that people at lower temperatures were also significantly less likely to be in the very dissatisfied group. This might indicate that our assumptions in calculating the neutral temperature were inaccurate, or that for office work people prefer to be a little cool than a little warm (mean temperature in the lower group was 22.1 ^{o}C and 24.3 ^{o}C in the upper group). The effect of carbon dioxide concentration was also consistent with other research [Seppanen et al., 1999; Apte et al. 2000], suggesting merit in maintaining carbon dioxide concentrations below typical recommended levels of 1000 ppm, which implies a ventilation system efficient at diluting potential air pollutants. Diffuser location, workstation size, and panel height were all non-significant, which is consistent with research showing that provided outdoor ventilation rates are scaled to the number of occupants the layout of offices and diffusers does not affect ventilation efficiency [Shaw et al., 2003]. RH was not significant.

The significant effect of gender may again be analogous to observed increases in SBS symptoms among women. Zweers et al. [1990] found that women were significantly more likely to complain about temperature and air quality. Zweers et al. [1990] also found a significant effect of age (younger people complained more), which we did not find.

Satisfaction with Lighting
The effect of panel height is consistent with simulation studies showing that lower panel heights provide better access to daylight, and better distribution of electric light [Newsham & Sander, 2003; Reinhart, 2002]. The effect of computer screen

glare was also expected, given previous research and the widespread recommendations to avoid such conditions [Veitch & Newsham, 1998; Veitch 2001; IESNA, 2000]. The benefit conferred by a desktop illuminance of 300 – 500 lx accords with recommended practice [IESNA, 2000], and with laboratory research that shows that most people choose illuminances in the recommended range when they have dimming control [Veitch & Newsham, 2000]. In addition Ooi et al. [1998] reported lower levels of SBS symptoms among people who said their lighting was neither too low nor too high (measured illuminance across their sample was 197-822 lux). It is interesting that the middle illuminance category confers an advantage even for peripheral workstations, where illuminances would tend to be higher due to available daylight. The effect of illuminance uniformity supports the findings of Slater & Boyce [1990], suggesting that a min/max ratio of 0.7 is good, but a ratio 0.5-0.7 is even better. The strong effect of window proximity was expected, the benefits of windows for occupant satisfaction through access to daylight and a view to the outside have been well documented [Farley & Veitch, 2001].

There were two effects that were present only for peripheral workstations. Firstly, smaller workstations conferred a higher risk of dissatisfaction. Being in a smaller workstation puts an occupant closer to a window, which may mean they are more likely to experience glare from daylight, and would be less able to move within their workstation to avoid it. Horizontal-to-vertical illuminance ratio also had a significant effect for peripheral workstations. A lower ratio means relatively more light from the side compared to light from above, which is symptomatic of daylight from windows, which is well-known to be desired by occupants [Farley & Veitch, 2001].

The only covariate effect was for job category in central workstations. People in higher job categories may be particularly unhappy with central workstations because a windowed office has traditionally been considered an amenity associated with higher rank and tenure.

Strengths and Limitations

The study methodology had some limitations, which may colour the interpretation of the results. The presence of the experimenters in the building may have caused occupants to behave differently, which may have affected the physical measurements, and answers to the questionnaire. It is also true that the 10-minute sample of physical data may not have represented typical conditions for that space. Participants were asked to consider the conditions at that moment when answering the questionnaire, but they may have taken a longer-term view, which would dampen the relationship between physical conditions and satisfaction data. Within the resources available to us, we selected buildings and office designs with a broad range of possible physical conditions and occupant characteristics, nevertheless, the sample was not perfectly representative of North American office buildings. However, most of these limitations are true of any field study.

This study also had methodological strengths. It is rare for a study in this domain to generate data comprising both physical and questionnaire data collected at the same time over a large sample size. It is likely that this combination of attributes enabled the analyses to demonstrate such a large range of effects in spite of the limitations described above. The fact that most of the effects agree with published research from other field studies and controlled laboratory experiments gives us greater confidence in their validity.

CONCLUSIONS

The results of this study suggest specific physical criteria to reduce the risk of dissatisfaction (and likely complaints) among open-plan office workers. These criteria are given below, along with the element of environmental satisfaction to which they particularly refer:

- Workstation area should be greater than 49 ft^2 (4.5 m^2) (Privacy & Acoustics, Lighting).
- Air temperature should be maintained within 0.5 ^oC of the calculated neutral temperature. Temperatures a little lower than this may also be acceptable (Ventilation).
- Carbon dioxide concentration, as an indicator of general ventilation efficiency, should be lower than 650 ppm (Ventilation).
- Reflected glare on computer screens should be minimized (Lighting).
- Illuminance should respect existing recommended practice; e.g. desktop illuminance 300 – 500 lux (Lighting).
- Desktop illuminance uniformity (min/max) should be 0.5 – 0.7 (Lighting).

The lighting analyses also suggest that panel height should be less than 54 inches (1.4 m). However, we hesitate to express this as a clear recommendation because of other work that suggests negative effects on acoustic privacy [Bradley, 2003a], and severe compromise of visual privacy. Further work on this aspect of workstation design is warranted.

A simple recommendation for window proximity is difficult because there are conflicting results from the analyses. For both privacy & acoustics and ventilation being distant from a window was beneficial, and being within 15 ft (5 m) of a window without a window in the workstation itself was more beneficial. For lighting the situation was reversed: being within 15 ft (5 m) of a window without a window in the workstation itself was beneficial, and having a window in the workstation was more beneficial. The appropriate choice for a workplace will depend on which aspect of satisfaction is most important to the employees and the tasks being performed. If this is not known, perhaps the best compromise recommendation would be:

- People should have a view to the outside through a window. However, people seated near windows should have provision to combat otherwise unusual visual privacy, acoustic privacy, and thermal comfort problems.

ACKNOWLEDGEMENTS

This paper uses data collected under the NRC/IRC project Cost-effective Open-Plan Environments (COPE), 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. The authors are grateful to the following individuals: John Bradley (acoustics expertise), Chantal Arsenault, 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, Clinton Marquardt, Jan Geerts (data analysis); Gordon Bazana and Cara Duval (data management). We are indebted to Don Hine of the University of New England for his comments on an early draft of this paper. Finally, we also thank the management and employees in the nine buildings for their participation.

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Table 1. Demographic characteristics of participants (N=779).

Age & Sex	Female 47.6 %	Male 51.5 %	Mean age (SD) = 36.2 (10.6) years		
Job categories		Administrative 27.1%	Technical 24.9%	Professional 38.4%	Management 8.6%
Education	High School 11.6%	Community College 15.1%	University Courses 14.6%	Undergraduate Degree 34.0%	Graduate Degree 22.7%

Table 2. The physical variables used as independent variables in the analyses.

Variable	Symbol	Description
Workstation Size*	WS	Square root of workstation area (length x width) [ft.]
Panel Height*	PH	Minimum partition height, excluding open sides and entrance [inch.]
Window Distance	WIND	Three categories, defined by building plans NO = no daylight (more than 15 ft from window) DL = daylight available (within 15 ft of a window), but no window in workstation WI = window in workstation
Speech Intelligibility	SII	Speech Intelligibility Index [ANSI, 1997], calculated using measured open-plan office speech levels, measured sound propagation, and daytime ambient sound level [range 0-1]
Ambient Noise	LNOISE	A-weighted ambient sound level during working hours [dBA], measured at head height of seated occupant
VDT Glare	VDT	Reflections in VDT screen, categorized by a panel from the photographs as low, medium, or high; see Figure 2 for examples
Desktop Illuminance	EDESK	Average illuminance over four points on the desktop [lux]
Illuminance Uniformity	UNIF	Minimum desktop illuminance over four points on the desktop / Maximum illuminance over those points
Horizontal to Vertical Illuminance Ratio	EH2V	Ratio of illuminance on top of cube to average on four vertical sides
Air Velocity	AIRVH	Air velocity at head height of seated occupant [ms^{-1}]
Air Temperature	TEMPH	Air temperature at head height of seated occupant [^{o}C]
Relative Humidity	RH	Measured at torso of seated occupant [%]
Air Diffuser Location	DL	inside workstation, or outside workstation
CO_2 concentration	CO2	Carbon dioxide concentration, measured at head height of seated occupant [ppm]

* North American office design practice uses British units for size measurements, therefore it was most sensible to describe our measurements this way. In the text we provide the metric equivalent.

Table 3. Composite Satisfaction Scales.

Scale	Individual Questionnaire Items (satisfaction with…)
Satisfaction with Privacy & Acoustics (SAT_PRIV)	… amount of noise from other people's conversations while you are at your workstation … frequency of distractions from other people … degree of enclosure of your work area by walls, screens or furniture … level of visual privacy within your office … distance between you and other people you work with … level of privacy for conversations in your office … amount of background noise (i.e. not speech) you hear at your workstation … size of your personal workspace to accommodate your work, materials, and visitors … your ability to alter physical conditions in your work area … aesthetic appearance of your office
Satisfaction with Ventilation (SAT_VENT)	… air movement in your work area … overall air quality in your work area … temperature in your work area
Satisfaction with Lighting (SAT_LIGH)	… quality of lighting in your work area … amount of lighting on the desktop … amount of light for computer work … amount of reflected light or glare in the computer screen … access to a view of outside from where you sit.

Table 4. Categorization of variables used in the analysis.

Variable	**Categories**				
SAT_PRIV	Bottom 20% ≤ 2.9	Top 20% ≥ 4.9			
SAT_VENT	Bottom 20% ≤ 3.0	Top 20% ≥ 5.6			
SAT_LIGH	Bottom 20% ≤ 3.8	Top 20% ≥ 5.8			
Job Category	Administrative	Technical	Professional	Managerial	
Gender	Female	Male			
Age	18-29	30-39	40-49	50-59	≥60
WS	<7	7-10	≥10		
PH	<54	54-66	≥66		
WIND	no	dl	wi		
SII	≤0.2	0.2-0.35	>0.35		
LNOISE	<42	42-48	≥48		
VDT	low	medium	high		
EDESK	<300	300-500	≥500		
UNIF	>0.7	0.5-0.7	≤0.5		
EH2V	<1.75	1.75-2.75	≥2.75		
AIRVH	<0.1	>=0.1			
TEMPH	<22.7	22.7-23.7	≥23.7		
RH	<30	≥30			
DL	inside	outside			
CO2	<650	≥650			

Table 5. Results of binary logistic regression on satisfaction with privacy and acoustics.

SAT_PRIV		**Bottom 20%** (n=164)	**Top 20%** (n=163)
Final Model: $\chi^2(13)=52.3$***		Nagelkerke *pseudo* R^2 = .203	
Predictor	**Odds Ratio (95% Confidence limits)**		
Job Category	1.37* (1.04 – 1.80)		
Gender	0.50** (0.29 – 0.85)		
Age	1.06*** (1.03 – 1.09)		
WS	**<7** (n=90) 10.46*** (3.43 – 31.88)	**7-10** (n=127) 1.74 (0.86 – 3.53)	**≥10** (n=110) Reference category
PH	**<54** (n=87) 0.74 (0.27 – 2.06)	**54-66** (n=149) 1.01 (0.49 – 2.09)	**≥66** (n=91) Reference category
WIND	**no** (n=136) 0.53* (0.29 – 0.96)	**dl** (n=54) 0.18*** (0.08 – 0.42)	**wi** (n=137) Reference category
SII	**<=0.2** (n=76) 0.89 (0.44 – 1.80)	**0.2-0.35** (n=116) 0.99 (0.56 – 1.75)	**>0.35** (n=135) Reference category
LNOISE	**<42** (n=41) 1.42 (0.55 – 3.65)	**42-48** (n=161) 1.29 (0.72 – 2.32)	**≥48** (n=125) Reference category

* p≤.05; ** p≤.01; *** p≤.001

Table 6. Results of binary logistic regression on satisfaction with ventilation.

SAT_VENT		**Bottom 20%** (n=194)	**Top 20%** (n=178)
Final Model: $\chi^2(15)=92.8$***		Nagelkerke *pseudo* R^2 = .299	
Predictor	**Odds Ratio (95% Confidence limits)**		
Job Category **Gender** **Age**	0.97 (0.76 – 1.25) 0.25*** (0.15 – 0.43) 1.00 (0.98 – 1.03)		
WS	**<7** (n=91) 0.46 (0.16 – 1.33)	**7-10** (n=157) 0.87 (0.44 – 1.72)	**≥10** (n=124) Reference category
PH	**<54** (n=96) 0.41 (0.14 – 1.22)	**54-66** (n=168) 0.93 (0.44 – 2.00)	**≥66** (n=108) Reference category
WIND	**no** (n=158) 0.47* (0.26 – 0.86)	**dl** (n=67) 0.33** (0.15 – 0.72)	**wi** (n=147) Reference category
AIRVH		**<0.1** (n=215) 0.73 (0.44 – 1.22)	**≥0.1** (n=157) Reference category
TEMPH	**<22.7** (n=88) 0.40* (0.20 – 0.82)	**22.7-23.7** (n=171) 0.32*** (0.17 – 0.58)	**≥23.7** (n=113) Reference category
RH		**<30** (n=195) 1.27 (0.74 – 2.18)	**≥30** (n=177) Reference category
DL		**inside** (n=280) 0.55 (0.29 – 1.03)	**outside** (n=90) Reference category
CO2		**<650** (n=214) 0.37*** (0.22 – 0.63)	**≥650** (n=158) Reference category

* $p \leq .05$; ** $p \leq .01$; *** $p \leq .001$

Table 7. Results of binary logistic regression on satisfaction with lighting, for all workstations taken together.

SAT_LIGH		**Bottom 20%** (n=172)	**Top 20%** (n=178)
Final Model: $\chi^2(17)=96.3^{***}$		Nagelkerke *pseudo* R^2 = .328	
Predictor	**Odds Ratio (95% Confidence limits)**		
Job Category **Gender** **Age**	1.17 (0.89 – 1.54) 0.99 (0.58 – 1.70) 1.00 (0.97 – 1.03)		
WS	**<7** (n=90) 2.28 (0.81 – 6.40)	**7-10** (n=148) 1.91 (0.89 – 4.12)	**≥10** (n=112) Reference category
PH	**<54** (n=103) 0.31* (0.12 – 0.84)	**54-66** (n=150) 0.58 (0.27 – 1.25)	**≥66** (n=97) Reference category
VDT	**low** (n=160) 0.37*** (0.21 – 0.67)	**medium** (n=71) 0.45* (0.22 – 0.91)	**high** (n=116) Reference category
EDESK	**<300** (n=88) 1.07 (0.55 – 2.08)	**300-500** (n=127) 0.51* (0.28 – 0.94)	**≥500** (n=135) Reference category
UNIF	**>0.7** (n=85) 0.64 (0.32 – 1.25)	**0.5-0.7** (n=117) 0.35*** (0.19 – 0.64)	**≤0.5** (n=148) Reference category
EH2V	**<1.75** (n=130) 0.81 (0.39 – 1.72)	**1.75-2.75** (n=125) 0.57 (0.28 – 1.13)	**≥2.75** (n=95) Reference category
WIND	**no** (n=135) 6.99*** (3.50 – 13.96)	**dl** (n=54) 3.36** (1.50 – 7.54)	**wi** (n=161) Reference category

* p≤.05; ** p≤.01; *** p≤.001

Table 8. Results of binary logistic regression on satisfaction with lighting, for central workstations only.

SAT_LIGH		**Bottom 20%** (n=73)	**Top 20%** (n=81)
Final Model: $\chi^2(15)=38.9$***		Nagelkerke *pseudo* R^2 = .310	
Predictor	**Odds Ratio (95% Confidence limits)**		
Job Category **Gender** **Age**	1.87** (1.20 – 2.92) 0.68 (0.30 – 1.55) 1.00 (0.96 – 1.04)		
WS	**<7** (n=59) 0.92 (0.16 – 5.46)	**7-10** (n=67) 0.75 (0.19 – 2.92)	**≥10** (n=28) Reference category
PH	**<54** (n=48) 0.19 (0.03 – 1.08)	**54-66** (n=70) 0.38 (0.10 – 1.39)	**≥66** (n=36) Reference category
VDT	**low** (n=64) 0.52 (0.20 – 1.30)	**medium** (n=41) 0.53 (0.19 – 1.50)	**high** (n=47) Reference category
EDESK	**<300** (n=56) 0.55 (0.18 – 1.68)	**300-500** (n=63) 0.35 (0.12 – 1.03)	**≥500** (n=35) Reference category
UNIF	**>0.7** (n=47) 0.80 (0.29 – 2.19)	**0.5-0.7** (n=43) 0.20*** (0.07 – 0.53)	**≤0.5** (n=64) Reference category
EH2V	**<1.75** (n=24) 3.26 (0.91 – 11.69)	**1.75-2.75** (n=52) 0.85 (0.34 – 2.15)	**≥2.75** (n=78) Reference category

* p≤.05; ** p≤.01; *** p≤.001

Table 9. Results of binary logistic regression on satisfaction with lighting, for peripheral workstations only.

SAT_LIGH		**Bottom 20%** (n=94)	**Top 20%** (n=112)
Final Model: $\chi^2(16)=41.8$***		Nagelkerke *pseudo* R^2 = .250	
Predictor	**Odds Ratio (95% Confidence limits)**		
Job Category **Gender** **Age**	1.15 (0.81 – 1.62) 0.68 (0.34 – 1.34) 1.02 (0.99 – 1.06)		
WS	**<7** (n=38) 4.53* (1.16 – 17.74)	**7-10** (n=92) 1.97 (0.79 – 4.94)	**≥10** (n=76) Reference category
PH	**<54** (n=56) 0.56 (0.17 – 1.93)	**54-66** (n=98) 0.82 (0.32 – 2.12)	**≥66** (n=52) Reference category
VDT	**low** (n=96) 0.31** (0.15 – 0.64)	**medium** (n=39) 0.61 (0.24 – 1.52)	**high** (n=69) Reference category
EDESK	**<300** (n=43) 0.97 (0.40 – 2.35)	**300-500** (n=74) 0.45* (0.20 – 0.99)	**≥500** (n=89) Reference category
UNIF	**>0.7** (n=41) 0.46 (0.19 – 1.13)	**0.5-0.7** (n=75) 0.42* (0.20 – 0.88)	**≤0.5** (n=90) Reference category
EH2V	**<1.75** (n=96) 0.21** (0.08 – 0.60)	**1.75-2.75** (n=75) 0.24** (0.09 – 0.65)	**≥2.75** (n=35) Reference category
WIND		**dl** (n=54) 2.04 (0.86 – 4.90)	**wi** (n=152) Reference category

* p≤.05; ** p≤.01; *** p≤.001

FIGURE LEGENDS

Figure 1. The cart and chair used for physical measurements, in a typical “cubicle” workstation.

Figure 2. Examples of VDT screen reflection categories. From left to right, low, medium, and high reflected glare.