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Effects of office environment on employee satisfaction: a new analysis

Abstract

Two large and detailed field studies of the effect of office environment parameters on aspects of environmental and job satisfaction were conducted. The first study focussed on open-plan offices in nine conventional buildings, whereas the second encompassed open-plan and private offices in 24 buildings (12 green and 12 conventional). The data collection for these studies was separated by approximately a decade, but the data collection methods, contexts, and analysis procedures were very similar. This offered the opportunity to compare the results of the studies at the workstation level, with the goal of identifying parameters consistent in affecting occupant satisfaction, and of exploring the effects of office type (open-plan vs. private) and building type (green vs. conventional). Satisfaction with acoustics and privacy was most strongly affected by workstation size and office type; satisfaction with lighting was most strongly affected by window access and glare conditions; and, satisfaction with ventilation and temperature was most strongly affected by pollutant concentration. Occupants of green buildings rated all aspects of environmental satisfaction more highly. Finally, job satisfaction was most strongly affected by pollutant concentration and office type.

Keywords: thermal comfort; acoustics; lighting; air quality; green buildings

1. Introduction

There is a considerable body of work investigating how the physical indoor environment in office buildings affects occupant comfort and well-being (e.g. Choi, Loftness, & Aziz, 2012; De Croon, Sluiter, Kuijer, & Frings-Dresen, 2005; Frontczak et al., 2012; Klitzman & Stellman, 1989; Pejtersen, Allermann, Kristensen, & Poulsen, 2006; Thayer et al., 2010; Yildirim, Akalin-Baskaya, & Celebi, 2007). This topic has grown in relevance with the importance of the green or sustainable buildings movement, in which various rating systems offer points for features related to indoor environment quality (Birt & Newsham, 2009; Lee, 2013; Todd, Crawley, Geissler, & Lindsey, 2010). Ideally these features and their determining metrics will be based on research results demonstrating measurable improvements in occupant outcomes associated with certain physical variables. Such results will carry more credibility if derived from data in real occupied buildings (field studies). Two original field studies designed to generate such information are described in this paper.

The first of these studies, part of the Cost-effective Open-Plan Environments (COPE) project conducted from 1999-2003, involved only open-plan offices. Open-plan offices have become the dominant interior design strategy for North American organizations, driven by lower real-estate costs and the notion that reducing physical barriers between individuals might also enhance team work (Brill, Margulis, Konar, & BOSTI, 1984; Sundstrom, 1987). However, persistent problems have been reported, with noise, distraction, and lack of privacy and control to the fore (Brill, Weidemann, & BOSTI, 2001; Brookes & Kaplan, 1972; Kim & de Dear, 2013; Lee, 1010; Marans & Spreckelmeyer, 1982; Mercer, 1979; Sundstrom, 1982; Zalesny & Farace, 1987).

The second study, a post-occupancy evaluation to address whether green buildings deliver superior performance (GreenPOE), was conducted from 2008-2012. Data were collected in open-plan and private offices, and in both green buildings and matched conventional buildings. Advocates suggest that green office buildings will deliver superior indoor environments, which will lead to more satisfied occupants with higher levels of well-being, and thus to better outcomes for their employers. There is much evidence that better indoor environments do lead to such positive outcomes (e.g. Newsham, Veitch, & Charles, 2008; Newsham et al., 2009; Singh, Syal, Grady, & Korkmaz, 2010; Thayer et al.; 2010), and some evidence that building tenants believe green buildings to be beneficial (PRNewswire, 2010). Prior research has shown that, in general, occupants of green buildings had higher satisfaction with air quality and thermal comfort, reduced acoustic satisfaction, and little gain in satisfaction with lighting (Birt & Newsham, 2009). Recently, several field studies have been published comparing indoor environment quality in green and conventional buildings, and the results have been mixed. Green buildings generally had higher levels of satisfaction, but in some cases the differences were practically small, and the importance of individual components of satisfaction has varied (Altomonte & Schiavon, 2013; Leaman, Thomas, & Vandenberg, 2007; Liang et al., 2014; Menadue, Soebarto, & Williamson, 2013; Newsham et al., 2013; Schiavon & Altomonte, 2014; Thatcher & Milner 2012).

In both studies described above detailed survey data and measurements of the physical environment in individual workspaces were collected, from which were derived statistically-significant relationships between the physical conditions and occupant comfort and well-being outcomes using similar methods. By considering the results of the field studies together relationships that are stable across the studies may be extracted, and the additional effect of office type (open-plan vs. private) and the effect of being in a green building, with other important variables controlled for, may be derived. The goal was to provide reliable information on which to base recommended practice for office space design and operation.

The results in this paper are derived from stepwise multiple regression analysis of data at the individual workstation level. The COPE study analyses have not been published in the peer-reviewed literature before, and were only available as a project report (Veitch, Charles, Newsham, Marquardt, & Geerts, 2003). GreenPOE analyses at the building average level have been published (Newsham et al., 2013), but the analysis at the workstation level is original. Thus this paper brings new data and analyses into the peer-reviewed literature, and, in combining the studies, extends the confidence and scope of the findings.

2. Methods & Procedures

The methods used in these investigations were very similar, but not identical. For brevity, only a summary of the methods is provided as more information is available in the detailed project reports (Newsham et al., 2012; Veitch et al., 2003).

2.1 COPE Methods

Nine buildings in six cities were visited. 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. Data were collected from a total of 779 open-plan workstations occupied by white-collar workers.

At each workstation, research staff approached the occupants individually to invite their participation; over 95% agreed to participate. Research staff conducted detailed physical measurements and recorded descriptive characteristics during a 10-minute period. Data collection was facilitated by a specially designed cart based on a modified office chair. Measurements included work surface illuminance, sound level at 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 (CO_2), total hydrocarbons and methane, as well as workstation size and partition heights. Additional acoustic and illuminance measurements were taken at night.

During the physical measurements, the occupant completed a 27-item questionnaire on a handheld computer concerning their satisfaction with their office environment. The questionnaire consisted of ratings of 18 specific environmental conditions, two overall ratings of environmental satisfaction, two items assessing job satisfaction, rankings of the relative importance of environmental features, and demographic characteristics (Veitch, Farley, & Newsham, 2002). Exploratory and confirmatory factor analyses were used to create three subscales of satisfaction from the 18 individual items (Veitch, Charles, Farley, & Newsham, 2007). Appendix A shows the individual items and their assignment to sub-scales. Thus, the final set of dependent variables for this field study comprised Satisfaction with Acoustics & Privacy (SAT_AP), Satisfaction with Lighting (SAT_L), Satisfaction with Ventilation & Temperature (SAT_VT), Overall Environmental Satisfaction (OES), and Job Satisfaction (JobSAT).

2.2 GreenPOE Methods

Data were collected in 24 office buildings located in Canada and northern United States. Building pairs were sampled, one green[1] and one conventional, that were as similar as possible (e.g. of approximately the same size and age, in the same climate zone, with the same/similar owner and/or employer, and occupants doing similar work). The investigation included open-plan workstations and private (or closed) workstations (with full-height walls and doors), occupied by white-collar workers. Building occupants were invited to complete an on-line questionnaire during a three-week period. The questionnaire had items related to environmental satisfaction, job satisfaction and organizational commitment, health and well-being, environmental attitudes, and commuting behavior. Key for this paper is that the environmental and job satisfaction questions were almost identical to those used in the COPE study (Appendix A). A total of 2545 questionnaire responses were received (response rate 39%).

During the three-week survey period, on-site physical measurements were carried out at a representative sample of workstations using an instrumented cart similar to the one used in the COPE study[2]. This mobile platform took a detailed snapshot of indoor environment conditions over a 10-15 minute period, including air temperature, air speed, relative humidity, formaldehyde, CO_2, carbon monoxide, quantity of respirable particles, illuminance, luminance mapping via high dynamic range photography (e.g. Inanici, 2006), and sound pressure level. In addition, workstation characteristics were recorded. Measurements were taken from a total of 974 workstations. Unlike the COPE study, the sampling procedure was not designed to obtain questionnaire and physical measurements from the same workstations in a given building. Nevertheless, in post-processing 230 workstations were identified that had both data types, and were thus amenable to the same data analysis approach as the COPE data.

2.3 Differences in Methods

In COPE the physical and survey data were collected simultaneously, whereas in the GreenPOE study the data came from within a three-week period. The survey invitation approach differed between the studies, with a greater risk of self-selection bias in the GreenPOE study. The GreenPOE survey had many more questions (each participant completed a core module, including the common environmental satisfaction questions, plus two of six supplementary modules, randomly assigned). The job satisfaction measure differed between the two studies: the COPE study used the average of two items, whereas the GreenPOE used a single item. The cart-based physical measurements had many items in common, but some differences; for example, the COPE study measured hydrocarbons and derived a measure of VDT reflected glare, whereas the GreenPOE study measured respirable particulates and HDR-based luminance maps. Nevertheless the methods were highly comparable overall, and very compatible for the comparison and integration of findings. Table 1 summarizes the physical measurements used in the subsequent analyses, highlighting those that were identical between the two studies and those that differed.

< Insert Table 1 here>

2.4 Data Analysis

Stepwise regression was used to explore relationships between survey outcomes (dependent variables) and physical measurements (independent variables). This method had already been used in the COPE analyses, so deploying it for the GreenPOE data offered the best opportunity to compare and extend the findings. Regression methods are broadly understood, provide output that is relatively easy to interpret, and offer a straightforward approach to statistically control for effects within a hierarchy.

One downside is that high intercorrelation between predictors entered in a model can create unexpected effects and mis-partition of variance that can cloud interpretation. Nevertheless, this is a generally accepted practice within the behavioural sciences (Kerlinger & Lee, 2000; Pedhazur, 1997; Tabachnick & Fidell, 2001)[3], and statistics, such as Tolerance, are available as guidance to ensure that excessively intercorrelated predictors are not employed.

Each dependent and independent variable was tested for normality. The criteria used were skewness values between +3 and -3, and kurtosis values between +8 and -8 (Kline, 1997). Non-normal variables were transformed to attain normality.

The order of entering predictor variables into the model was very similar between the two datasets, but not identical. The COPE results are archival and not open to modification, whereas GreenPOE analysis choices were made partly to compare to COPE, but also to pursue independent interests. In general, demographic variables were entered in the first step as a block. Next, workstation characteristics were entered as a block. This was followed by physical predictors specific and conceptually-related to the dependent variable of interest; these were entered one-at-a-time. In the COPE analyses the presence of a window was included in the workstation characteristics block for outcomes not related to lighting, and as a separate step for lighting-related analyses; in the GreenPOE analyses the presence of a window was always entered independently immediately after the workstation characteristics block. Note that in the vast majority of cases the windows in the study buildings were not openable. In the COPE analyses a standard set of predictors was retained in the final model without regard to the statistical significance of its contribution; in the GreenPOE a greater number of variables was explored, and a filtering approach was adopted which used statistical significance and Tolerance[4] metrics as criteria for retention of a variable in the model, although some non-significant predictors were retained for conceptual interest and consistency.

3. Results

3.1 Descriptive statistics

Examination of descriptive statistics establishes the similarity of the samples. All of the COPE data came from open-plan workstations in conventional buildings, therefore descriptive data for the sub-samples of GreenPOE data from open-plan workstations in conventional buildings and green buildings are also provided. The sub-samples from the GreenPOE study from all workstations in conventional buildings, and all workstations in green buildings, were also examined.

Table 2 summarizes the demographic data of the participants in the two studies. For the most direct overlap between the two studies (COPE vs. GreenPOE open-plan in conventional buildings sub-sample), note that the COPE sample is gender balanced, whereas the GreenPOE sub-sample is majority female. The job type categories are open to interpretation by the respondents, though the rank-ordering of category populations is essentially the same. In both samples, the majority of participants have at least an undergraduate degree, although the GreenPOE sub-sample had higher educational attainment.

< Insert Table 2 here>

Table 3 summarizes basic workstation characteristics in the two studies. Comparing the COPE group to the GreenPOE open-plan in conventional buildings sub-sample, note that the basic workstation characteristics were very similar.

< Insert Table 3 here>

Table 4 shows descriptive statistics for the measured physical variables common in the two studies. Comparing the COPE group to the GreenPOE open-plan in conventional buildings sub-sample, note that in general the average values were quite similar. There were some relatively small differences, but they could not be considered universally better in one sample: the COPE group experienced slightly lower air velocities, lower illuminances, and noisier conditions.

< Insert Table 4 here>

Table 5 shows descriptive statistics for the dependent variables common in the two studies. Comparing the COPE group to the GreenPOE open-plan in conventional buildings sub-sample, note that the COPE group reported higher mean ratings for OES, SAT_AP, and SAT_VT, and lower mean ratings for SAT_L and JobSAT. So, although there were differences in the samples, they were not universally better in one sample.

< Insert Table 5 here>

Collectively, these descriptive statistics show that despite there being approximately 10 years between measurements, the basic office conditions were not radically different between the samples.

3.2 Stepwise regressions

Details of the analyses are presented in the following tables (associated bivariate correlation tables for the predictors in each GreenPOE analysis are shown in Appendix B). However, the goal of this paper is not to analyze the details of each step of each set of results, but rather to look for important predictor variables or concepts that are consistent across the two studies. Further, how the GreenPOE results extend the findings to show the effects of having a private office, and of being in a green building is also of interest. The GreenPOE analyses use the full sample unless otherwise specified, nevertheless, the number of workstations (N) differs between analyses as the number of missing cases differs between variables used in each table. Effect sizes (R^2) are interpreted using Cohen's (1988) guidelines for small (1%), medium (9%), and large effects (25%).

3.2.1 Satisfaction with acoustics and privacy (SAT_AP)

Table 6 shows the analysis results for COPE (a) and GreenPOE (b); the GreenPOE model explains substantially more variance in satisfaction with acoustics and privacy. The COPE model suggests that in open-plan offices workstation size is a significant predictor, with larger workstations associated with greater satisfaction. This makes sense as larger workstations place occupants further apart, reducing the number of people available to overhear conversations and create sources of unwanted sound, facilitates sound attenuation, and likely also supports visual privacy. The GreenPOE data confirm this finding. The GreenPOE result also shows that after accounting for workstation size, having an office with full-height walls and a door (ClosedWS) also confers greater satisfaction, this has obvious face validity (Frontczak et al., 2012; Kim & de Dear, 2013; Schiavon & Altomonte, 2014). The GreenPOE result further shows that after accounting for other factors, being in a green building increases satisfaction with acoustics and privacy. This was unexpected given prior work (Birt & Newsham, 2009; Leaman et al., 2007; Menadue et al., 2013; Schiavon & Altomonte (2014)). In North America, lower satisfaction might be a logical consequence of the prevailing LEED credit system, which offers credits for building design features such as low partitions to allow daylight to penetrate and provide views to the outside, and encourages hard ceilings and floors to improve air quality. However both of these features have negative effects for acoustics, particularly speech privacy (Bradley & Wang, 2001).I It is not obvious from the presented descriptive variables why satisfaction was higher in green buildings, however, Liang et al. (2014)

reported a similar finding. The studies were consistent in that none of the typical physical measures of the acoustic environment (e.g. AI, SII, SNA) were predictive of SAT_AP.

< Insert Table 6a here>

< Insert Table 6b here>

A subset of the GreenPOE participants answered more detailed questions on their acoustic environment, including a question specific to annoyance with speech from neighbours (scale 1-7, with higher values indicating greater annoyance). A stepwise regression on this dependent variable yielded a model with a large fraction of variance explained (Table 7), in which the only significant predictor at the final stage was ClosedWS, with the effect in the expected direction. Again, there was no significant effect of AI, SII, SNA. Of course, these are only entered into the model after workstation characteristics, and workstation characteristics are factors that contribute to the physical acoustic measures. Thus, entering the workstation characteristics first dilutes the potential effect of the physical variables describing of the acoustic environment. This simply highlights the intercorrelation issues in such analysis.

< Insert Table 7 here>

3.2.2 Satisfaction with lighting (SAT_L)

Table 8 shows the analysis results for COPE (a) and GreenPOE (b); the GreenPOE model explains substantially more variance in satisfaction with lighting. The COPE model suggests that access to a window is a significant predictor, with more window access providing greater satisfaction. This is in agreement with prior research on access to daylight and outside views (Farley & Veitch, 2001; Frontczak et al., 2012; Galasiu & Veitch, 2006; Yildirim et al., 2007). The GreenPOE data confirms this strong finding for both open-plan and private offices. Both studies concur that physical variables related to the luminous environment were predictive of SAT_L. Metrics of glare were associated with lower satisfaction (represented by VDT_CAT for the COPE study and DGP for the GreenPOE study), again, this is consistent with prior research (Choi et al., 2012; Hirning, Isoardi, & Cowling, 2014). Note that in the GreenPOE study higher overall light level (LumAbMLN, IllumBelow) was associated with better satisfaction; the variable CUBEDAYT in the COPE analysis showed a similar relationship, but did not maintain significance in the final step of the model. The GreenPOE result further shows that after accounting for other factors, being in a green building increases satisfaction with lighting. This finding is supported by Leaman et al. (2007) and Liang et al. (2014), but is contradictory to the findings of others. For example in Menadue et al. (2013) there was no significant difference in overall lighting conditions across a sample of green and conventional buildings, with electric lighting perceived as brighter in the conventional buildings, and daylighting brighter in the green buildings; in Thatcher & Milner (2012) employees of a financial institution reported significantly worse lighting conditions after moving to a new green building, but this was attributed to commissioning issues with an advanced lighting system; Altomonte & Schiavon (2013) also showed lower satisfaction with the amount of light overall in green buildings.

< Insert Table 8a here>

< Insert Table 8b here>

3.2.3 Satisfaction with ventilation and temperature (SAT_VT)

Table 9 shows the analysis results for COPE (a) and GreenPOE (b); the GreenPOE model explains a little more variance in satisfaction with ventilation and temperature. Both models indicate that females were less satisfied, which has been observed in other research (e.g. Zweers, Preller, Brunekreef, & Boleij, 1992; Karjalainen, 2012). In both studies, a measure of air quality was predictive of SAT_VT in the expected direction. In the COPE study higher CO_2 concentrations were associated with lower satisfaction. The GreenPOE study did not show an effect of CO_2, but did show an effect of particulates (not measured in COPE): higher levels of PM2.5 were associated with lower levels of satisfaction, as expected from the work of others (Newsham et al., 2013; Wolkoff, 2013). The GreenPOE result further shows that after accounting for other factors, being in a green building increases satisfaction with ventilation and temperature.

< Insert Table 9a here>

< Insert Table 9b here>

3.2.4 Overall Environmental Satisfaction (OES)

The effects of physical predictors on OES in the COPE study were small or non-existent, and of small practical value; therefore, for brevity the details are omitted here (see Veitch et al. (2003) for details). Table 10 shows the regression results for the GreenPOE study, which shows an overall medium-sized effect. After accounting for other factors, being in a green building increases overall environmental satisfaction. This is consistent with the findings from the individual satisfaction components above. The lack of other significant predictors is noteworthy, it seems that although presence of a window and a door, for example, are important when considering specific aspects of the environment, they are less important when considering the environment as a whole. This could be because OES is more strongly influenced by variables not considered here, or because the effect of the measured variables is not direct, but is mediated by the effects on individual components of satisfaction (Veitch, Charles, Farley, & Newsham, 2007). Again, recall that the vast majority of windows in the sample were not openable, and thus the broader effects on environmental satisfaction beyond daylight availability observed in other studies with openable windows would not apply.

< Insert Table 10 here>

3.2.5 Job Satisfaction (JobSAT)

Table 11 shows the analysis results for COPE (a) and GreenPOE (b); the GreenPOE model explains a little more variance. Separate COPE models were developed for the different aspects of the indoor environment; for brevity only the model related to ventilation and temperature is shown, as the other models showed minimal effects (see Veitch et al. (2003) for details). As with the Sat_VT analysis, in both studies measures of air quality were predictive of JobSAT in the expected direction. In the COPE study higher concentrations of both CO_2 and a composite measure of pollutants were associated with lower satisfaction. The GreenPOE study did not show an effect of CO_2 (and did not have the same pollutant cocktail parameter), but did show an effect of particulates: higher levels of PM2.5 were associated with lower levels of satisfaction. The GreenPOE result further shows that being in an enclosed office is associated with better job satisfaction (consistent with Lee (2010)), although, intriguingly, lower panel heights were associated with better satisfaction in the COPE study. Unlike all other survey outcomes in this paper, being in a green building was not associated with higher levels of job satisfaction.

< Insert Table 11a here>

< Insert Table 11b here>

4. Discussion & Conclusions

One consistency among the regression results is that variance explained was generally higher for the GreenPOE regressions, even though the sample size was smaller. This might have been because the GreenPOE sample contained more variability in office and building types, leading to somewhat larger ranges in measured predictor variables (Table 4) and probably to greater variability in other factors that were not explicitly measured. Table 4 also shows that, in general, the physical conditions in all buildings were within ranges of prevailing recommended practices. A low frequency of poor conditions means that the range in independent variables is constrained, and therefore results that explain only a small-to-medium percentage of variance are to be expected. This is common in this type of research; for example, the variance in perceived thermal comfort explained by measured temperature is typically around .15 (Newsham & Tiller, 1997). This reinforces the importance of focussing on consistent elements between studies to be confident in effects of this size. It also suggests that commonly measured physical parameters might not as important as we think in determining occupant satisfaction (provided conditions aren't extreme or obviously unhealthy). Perhaps human perception is a better indicator of integrated indoor environment effects, or perhaps our current standards do not yet capture the most influential variables; this may be a topic for future research. Nevertheless, small effects can be practically important. As stated in the Introduction, the linkages between an improved indoor environment and better job satisfaction and other organizational productivity metrics are well-established, and minor improvements in organizational productivity can have large payoffs (Newsham et al., 2009; Sullivan, Baird, & Donn, 2013).

Table 12 summarizes the variables that were consistent in predicting satisfaction outcomes across the two studies, and the instances where being in a private office, and in a green building, were associated with satisfaction outcomes in the GreenPOE study. In most cases, these relationships were consistent with prior research, and would have been entirely expected based on "common sense", however, it is valuable to see these emerge in studies a decade apart in the scientifically-uncontrolled, and practically-important environment of real buildings. Perhaps just as interesting is the set of predictors that were not associated with outcomes.

For example, for acoustics and privacy, larger workstations, and workstations with full-height walls and doors, were the route to better satisfaction, and other measured subtleties of acoustic design were of little value. However, current and recent trends in office design are generally proceeding counter to this in reducing the space per person and bringing down physical barriers between workers (PRNewswire. 2012). Job satisfaction was also improved by having a private office, although this could be confounded by job type.

For satisfaction with ventilation and temperature, thermal variables played a minor role across the two studies, whereas measures of air quality were important. In the COPE study CO_2 was the most important variable in this regard, and higher CO_2 levels typically indicate poorer ventilation efficiency; in GreenPOE the most important variable related to respirable particulates, which could be related to both ventilation efficiency and pollutant source control. Of all the measured physical indoor environment parameters, these are the only factors that are also predictive of job satisfaction.

Access to a window in one's own workstation was a major factor in satisfaction with lighting, though not for other the aspects of occupant satisfaction considered in this paper, this might be because in most cases windows were not openable and therefore the potential for effects on air quality and thermal comfort were diminished. Glare was a consistent negative for lighting satisfaction; in COPE this was expressed via the only glare measure employed, reflected glare in the computer screen, whereas the GreenPOE study used a measure of glare in the broader indoor environment.

Overall Environmental Satisfaction (OES) showed no consistent relationship with specific physical variables, although Veitch et al. (2007) demonstrated using structural equation modelling that OES is strongly determined by the individual satisfaction measures.

< Insert Table 12 here>

It is striking that being in a green building improved many outcomes. Table 4 suggests no obvious pattern of major differences in the measured parameters that might explain this, especially as in the stepwise regressions such differences are already (partially) controlled for. It has been proposed that occupants of green buildings will be more tolerant of building conditions, perhaps due to an attitudinal bias towards sustainability (Gou, Prasad, & Lau, 2013; Leaman & Bordass, 2007; Liang et al., 2014). The GreenPOE survey contained items related to environmental attitudes (Dunlap, Van Liere, Mertig, & Emmet-Jones, 2000), but the derived New Environmental Paradigm scale (higher values indicating greater environmental concern) did not differ between the GreenPOE sub-samples in green and conventional buildings (means: green (N=35) 3.39, conventional (N=27) 3.67; t=1.75, n.s.). It seems that occupancy of a green building might have conferred satisfaction benefits due to physical or attitudinal differences in parameters that were not measured in the study, and this is an avenue for future research to explore.

This analysis supplements prior results from these two studies (Newsham et al., 2013; Veitch et al., 2003). Although there may be differences in the individual items shown to be predictive and at what levels, clear patterns of important indoor environment variables emerged. In general, these are aligned with existing recommended practice; there were no great surprises in the variables found to be predictive of occupant satisfaction, these results are confirmatory and incremental to our knowledge based on the latest data. Nevertheless, given the relative paucity of comprehensive post-occupancy data from office buildings, the results emphasize aspects that are the most important and worthy of further attention by researchers and by designers seeking to optimize the experience of office populations.

Overall, these results do support the proposition that green office buildings, on average, provide a superior level of indoor environment quality, and that designers who follow green principles are more likely to satisfy their clients. However, while some factors associated with better indoor environments are not controversial (e.g. reduced glare and air pollutants), others might be difficult to provide given current trends and business drivers. For example, although green building systems generally provide credits for access to a view to the outside, the results in this paper suggest a window in each workstation should be provided to maximize satisfaction with lighting. This is incompatible with current trends in office form and interior design (at least in North America), which favour deep plan buildings and reduced "ownership" of the perimeter. Similarly, satisfaction with acoustics and privacy was enhanced in these results by having larger offices with full-height walls and a door, whereas the trend in office design is to ever more open spaces with smaller personal space allocations. The challenge for designers is to find suitable compromises between these factors, there is no simple solution, but results like these at least help to focus attention on the most important issues.

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Endnotes

1. Buildings were classified as green using various methods. In all but three cases, the buildings were LEED certified, or had applied for LEED certification, at some level. In the other cases an alternative rating system was used, or the owner had taken substantial and documented steps toward sustainability. Also note that three of the green buildings were renovations, not new build.
2. We chose temporarily unoccupied workstations because this caused less disturbance to occupants, which was an important practical consideration for gaining access to buildings. These locations were next to occupied workstations, and were therefore considered representative of the environment to which the occupants and survey respondents were exposed.
3. Another appealing approach is to use Hierarchical Linear Models (HLM). In this approach a hierarchy of levels of analysis is developed, in this case individual responses would be grouped within buildings, and buildings could then be grouped by region, or by green designation, for example. Conceptually, relationships are then explored within a building and then checked for consistency across buildings. The proposed advantage of this approach is that is controls for exogenous differences between units at the upper levels of the hierarchy (e.g. buildings) that are not under the control of, or of interest to, the researcher. In many contexts (a common one is student attainment within classrooms within schools) this is valuable in isolating the effects of the variables under study. However, in this case, the physical differences in the indoor environment resulting from differences in buildings are of interest, and these effects may be compromised with a HLM approach. The preparatory work for the original COPE analysis employed many tests to demonstrate that the buildings were not excessively different and to justify pooling data into a single regression model. In the GreenPOE study the building selection stage ensured greater similarity of buildings. Although stepwise regression was the primary analysis method for the GreenPOE data, parallel models were also developed using HLM with results similar enough that final conclusions would not be affected.
4. Tolerance is an indication of the percent of variance in the predictor that cannot be accounted for by the other predictors, hence very small values indicate that a predictor is redundant, and values less than .10 may merit further investigation

Appendix A

The individual items in the environmental features ratings in the COPE and GreenPOE studies were worded identically. The only difference was in the general framing of the items, in the COPE study the survey was presented to each participant on a handheld device and on-screen instructions directed the participant to express their satisfaction with the conditions at that moment. In the GreenPOE study the survey was presented on-line, with no explicit instructions regarding the timeframe of conditions that should be considered.

< Insert Table A1 here>

For overall environmental satisfaction (OES), there was a small difference in the wording of the first item relating to self-estimated productivity, as shown in Table A2.

< Insert Table A2 here>

< Insert Table A3 here>

Appendix B

Bivariate correlation tables for each of the stepwise regression analyses conducted with the GreenPOE data.

< Insert Table B1 here>

< Insert Table B2 here>

< Insert Table B3 here>

< Insert Table B4 here>

< Insert Table B5 here>

< Insert Table B6 here>