Effects of building characteristics on self-reported productivity of office workers: the base study

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ABSTRACT

The objective of this study was to evaluate the effects of building characteristics on self-reported productivity using the Building Assessment Survey Evaluation (BASE) dataset. Of the respondents surveyed, 28% reported one or more lost workdays over the last month due to building-related symptoms, and 40% reported reduced ability to work. Using generalized estimating equations, we found significant negative adjusted associations for design space per workstation (odds ratio (OR) = –0.01, 95% confidence interval (CI = –0.03, –0.002) and number of windows per occupant (OR = –0.26, CI = –0.46, –0.06) with reporting a reduced ability to work on one or more days over the past month. For reporting one or more lost workdays over the past month, we found a significant negative association for design space per workstation (OR = –0.01, CI = –0.02, –0.002) and a positive association for location on the West Coast (OR = 0.21, CI = 0.03, 0.39). The negative associations observed indicate that decreases in space and windows per occupant are related to an increased likelihood of self-reported productivity decrements. We estimate that the cost of lost productivity due to building-related symptoms in this dataset is $208 227 per building. These results underscore the importance of space and lighting in office environments.

INDEX TERMS

Productivity; Building-related symptoms; Economics; Office building; Epidemiology

INTRODUCTION

Decrements in worker productivity due to nonspecific building-related symptoms (NSBRS) reported in non-industrial indoor environments can have significant economic implications; however, the aetiology behind NSBRS remains largely unknown. Furthermore, there is limited information in the literature regarding the impact of NSBRS on productivity. In a telephone survey of 600 US office workers conducted by Woods *et al*. (1987), 20% of the respondents stated that their performance was hampered by indoor air quality, but the study did not provide information regarding the magnitude of the productivity decrement. Raw *et al*. (1990), in a study of office workers in the United Kingdom, reported an average self-reported productivity decrement of 4% due to physical conditions at work. An experimental study (Menzies *et al*., 1997) found that workers with individually controlled ventilation systems reported that IAQ at their workstation improved productivity by 11% relative to a 4% decrease in productivity in a control population of workers. Other studies have examined the relationship of NSBRS and productivity using computer-based, possibly more objective, tests, and have in general corroborated the negative impact of symptoms on performance (Nunes *et al*., 1993; Myhrvold *et al*., 1996; Myhrvold and Olsen, 1997). Moreover, laboratory-based investigations (Wargocki *et a*l., 1999, 2000) have shown that increases in symptoms were associated with decreased performance. The potential yearly productivity gains in the United States from reductions in NSBRS have been estimated at $76 billion (Fisk, 2000).

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Changes in worker performance have also been associated with certain building or environmental factors. For example, the impacts on performance of temperature (e.g. Wyon, 1996; Menzies *et al*., 1997) and lighting (e.g. Hedge *et al*., 1995) are both well-documented. Recently, a review by Heath and Mendell (2002) found that some aspects of IEQ, including low ventilation rate and less daylight or light, may reduce the performance of occupants. Potential savings resulting from increases in performance through pathways unrelated to NSBRS (i.e. direct improvements to indoor environments) have been estimated by Fisk (2000) at $19 to $190 billion.

The primary objective of this study was to evaluate the effects of selected building characteristics on self-reported workplace productivity using the Building Assessment Survey Evaluation (BASE) dataset. Our secondary objective was to estimate the economic impact of the productivity decrements reported in the BASE study. The BASE study is an observational study conducted by the US EPA in 100 representative office buildings from 1994 to 1998.

METHODS

We used the Building Assessment Survey Evaluation (BASE) dataset, collected by the US EPA in 100 representative office buildings from 1994–1998 (see Brightman *et al*., 1996, 1997, 1999; Womble *et al*., 1995, 1996 for additional details). The BASE questionnaire was 10 pages long and took about 30 min to complete. BASE investigators administered the questionnaires to as many of the respondents as possible in a randomly selected survey area. Symptoms were presented in a page-long table. For each of the 19 symptoms, respondents chose how often the symptom had occurred over the previous4 weeks (symptom frequency) and whether the symptom lessened after they left work (work-relatedness). Below the table, two questions regarding productivity were asked:

> *In the LAST FOUR WEEKS how often have any of the symptoms listed above reduced your ability to work? ____days. In the LAST FOUR WEEKS how often have any of the symptoms listed above caused you to stay home or leave work? ___days.*

We coded a dichotomous variable for each of these questions with a cut-off of one or more days and created a subset of those data for which there were complete records for both productivity variables. We tested the association between each of the productivity variables and building characteristics, using generalized estimating equations with an exchangeable covariance structure and a logistic link (proc genmod), in order to adjust for potential clustering of symptoms within buildings. Odds of lost days or lost ability to work were first calculated univariately and then multivariately, successively adjusting for the self-reported characteristics. Statistical analyses were conducted using the SAS 8.02 (SAS Institute, Cary, NC) and S-Plus 6.0 (Insightful, Cambridge, MA) software packages. Statistical significance in all analyses was based on $\alpha = 0.05$.

RESULTS

The total number of respondents answering both self-reported productivity questions was 3684. Respondent characteristics are shown in Table 1. Of the respondents surveyed, 28% reported one or more lost workdays over the last month, and 40% reported a reduced ability to work on one or more days over the last month.

Table 1 Demographic and NSBRS prevalence in US office workers participating in the BASE Study and answering both self-reported productivity questions, 1994–1998 (n = 3684)

Variable	% Respondents
Gender	
Male	34.2
Female	65.8
Age	
Under 30	28.9
Under 40	32.6
Under 50	22.3
50 and over	16.2
Asthma	11.5
Dust/mould allergy	33.5
Current smoker	15.0
Frequent work-related nonspecific building-related symptoms	
Musculoskeletal symptoms	4.4
Mucosal irritation symptoms	4.6
Neuropsychological symptoms	6.5
Lower respiratory symptoms	4.4
Self-reported productivity	
Lost workdays (staying at home)	27.6
Reduced ability to work	40.1

Modelling was carried out using generalized estimating equations to adjust for building clustering. In univariate models of building characteristics and staying at home, we found statistically significant ORs) for present water damage, workstation design space and number of windows per occupant (data not shown). For reduced ability to work, significant ORs were found for location of building on the West Coast and workstation design space (data not shown).

Results from multivariate models, adjusting for age, gender, asthma, dust/mould allergy, and smoking, are shown in Table 2. For lost productivity due to staying at home, the negative associations for design space per workstation and number of windows per occupant remained significant, indicating that a reduction in space or windows is related to an increased likelihood of reporting at least one lost workday over the past month. For reduced ability to work, design space per workstation and location of building on the West Coast retained significance in multivariate models. Again, the negative association with design space per workstation indicates an increased likelihood of reporting at least one day of reduced ability to work over the past month with a reduction in space per workstation. The positive association with location on the West Coast means that such a location is associated with an increased likelihood of reporting productivity decrements.

Table 2 Estimated effect of selected building characteristics on self-reported productivity in US office workers participating in the BASE Study. Results adjusted for age, gender, asthma, dust/mould allergy and smoking. Bold font indicates statistical significance ($p < 0.05$)

Building characteristic	Reduced ability to work		Stay at home	
	Estimate	95% CI	Estimate	95% CI
Occupant density	1.22	–0.64, 3.0	1.85	–0.12, 3.82
Age of building	–0.12	–0.30, 0.06	–0.07	–0.28, 0.15
Frequency of filter replacement	–0.02	–0.12, 0.08	–0.04	–0.15, 0.07
Frequency of HVAC inspection	0.007	–0.04, 0.06	–0.01	–0.06, 0.04
Location on West Coast	**0.21**	**0.03, 0.40**	0.16	–0.09, 0.40
Location in West	0.09	–0.16, 0.35	–0.10	–0.16, 0.36
Location in Midwest	–0.08	–0.29, 0.14	–0.04	–0.28, 0.20
Location in Southeast	–0.13	–0.31, 0.06	–0.12	–0.35, 0.11
Past water damage	0.005	–0.18, 0.19	0.01	–0.20, 0.22
Present water damage	0.16	–0.03, 0.35	0.17	–0.03, 0.37
Frequency of cleaning	0.05	–0.02, 0.13	0.03	–0.10, 0.15
Design space per workstation	**–0.01**	**–0.02, –0.002**	**–0.01**	**–0.03, –0.002**
Windows per occupant	–0.02	–0.21, 0.16	**–0.26**	**–0.46, –0.05**
Operable windows per occupant	0.13	–0.10, 0.35	–0.11	–0.04, 0.18
Smoking permitted in building	0.14	–0.12, 0.40	–0.25	–0.72, 0.22

ECONOMIC IMPLICATIONS

Translating the self-reported productivity decrements into costs was carried out using the following framework. Using the subset of records for which both productivity questions were answered ($n = 3684$), the mean number of days of reduced ability to work and staying at home were calculated at 1.672 and 0.594, respectively. These figures were converted into average annual reductions in productivity of 7.717% and 2.742% based on a 260-day work-year.

In 2000, the US GDP was $9 963 100 000 000 (Statistical Abstract of the United States, 2001). We counted the number of workers carrying out office-related jobs (again, for 2000); this is 72 061 000. If approximately 50% of the GDP comes from office-related work (as per Fisk, 2000), we can then calculate an average GDP per office worker of $69 129. For each of

the two productivity questions, we calculated an average loss per respondent due to productivity decrements of $4957 (reduced ability to work) and $1895 (staying at home). Accounting for the total number of respondents (in the subset of respondents with non-missing values for the self-reported productivity questions), this works out to be $18 261 588 for reduced ability to work and $6 983 148 for staying at home, for a total of $20 822 697 overall. For the 100 buildings comprising the BASE Study, this represents $208 227/buildings, assuming an equally proportional loss in productivity in all buildings.

DISCUSSION AND CONCLUSIONS

We found significant negative associations between workstation space and windows with self-reported measures of productivity, suggesting that increased space and day lighting could lead to increased productivity. There is little available information with which to compare these findings, although they are consistent with recent studies by the Heschong Mahone Group (1999a, b), who reported positive impacts of day lighting on performance in schools and retail establishments. The positive finding of West Coast location with reduced ability to work is interesting and worthy of further exploration. Additional details regarding the context and interpretation of the modelling results will be presented at *Healthy Buildings 2003*.

The economic analysis presented, although subject to substantial uncertainty, illustrates the potentially significant economic impact of productivity decrements due to building-related symptoms in the office environment. This is particularly true as the BASE buildings are non-complaint spaces and thus are representative of current US building stock. Productivity losses in complaint buildings would be expected to be significantly higher.

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