Effects of indoor air quality on office workers' work performance—a preliminary analysis

H.J. Chao[a,]*, Joel Schwartz[b], D.K. Milton[b], M.L. Muilenberg[b], H.A. Burge[b]

[a]*Graduated Institute of Public Health, Taipei Medical University, Taiwan;* [b]*Department of Environmental Health, Harvard School of Public Health, USA*

ABSTRACT

We conducted an epidemiological study to examine the associations between indoor climate and office workers' health and working efficiency. We investigated four office buildings in Massachusetts, USA, beginning May 1997 over 1 year. Ninety-eight participants in 21 offices were recruited. We measured relative humidity, temperature and carbon dioxide continuously at each sampling location, along with other environmental parameters. We administered questionnaires weekly to collect information on workers' daily symptoms. A standardized computer test, *NovaScan A*, was taken by the participants once a week to evaluate their working efficiency. In the preliminary data analysis, we found higher relative humidity, higher temperature and lower respiratory symptoms would decrease workers' performance. Other factors associated with working efficiency include education, types of workstation and number of people in the office. Our findings provide essential information on preliminary results of the associations between indoor air quality, workers' health and productivity.

INDEX TERMS

Building investigation; Building-related symptoms; IAQ assessment; Productivity

INTRODUCTION

Problematic indoor environment and building characteristics not only cause health symptoms, but also unnecessary costs (Woods *et al.*, 1987; Woods, 1989). Fisk and Rosenfeld indicate that crude estimates of the magnitude of productivity gains that may be obtained by providing better indoor environments are very large. For the US, the potential annual savings and productivity gains are \$6–19 billion from reduced respiratory disease, \$1–4 billion from reduced allergies and asthma, and \$10–20 billion from reduced sick building symptoms. The potential financial benefits of improving indoor environments exceed costs by a factor of 18–47(Fisk and Rosenfeld, 1997).

Although the productivity loss due to indoor environment seems huge, limited studies were conducted to demonstrate the causal link (Raw *et al.*, 1990; Hall *et al.*, 1991; Newsham *et al.*, 1997). The major problem is the lack of appropriate methods to evaluate worker performance objectively. In addition, it is more challenging to measure the performance of office workers,

* Corresponding author.

since office workers are generally not engaged in the production of standard times that can simply be counted as a measure of performance. The study design may also contribute to the difficulty to evaluate the relationship. Since important effects might be periodic or transitory, most studies, which are cross-sectional, might either overlook the effect or could not determine the cause–effect relationship. Longitudinal studies would be more appropriate to detect the effects, but they are more time and money consuming.

In view of the need to investigate the impact of indoor environment quality on working efficiency, we conducted a longitudinal study to evaluate the association. In this 1-year study, all the participants were asked to take a standardized, well validated computer test, *NovaScan A*, once a week to measure their work performance. The environmental factors and other measurements were also evaluated longitudinally. This preliminary analysis focused on the effects of thermal comfort factors and daily symptoms on working efficiency.

METHODS

Detailed study design has been described elsewhere (Chao *et al.*, 2002, 2003). In brief, 21 offices with open stations (low partitions) in four office buildings in Boston, Massachusetts, USA, were investigated beginning May 1997 over 1 year. Ninety-eight occupants were recruited. Intensive environmental sampling was conducted every 6 weeks resulting in 10 sampling events at each sampling location over the study year. Temperature, relative humidity (RH) and CO_2 levels were measured continuously at each sampling site (Chao *et al.*, 2002). A one-page questionnaire was administered weekly to collect participants' daily work-related symptoms and absence. Four categories of daily work-related symptoms were investigated, including non-specific symptoms (e.g. headache, drowsiness), lower respiratory symptoms (e.g. shortness of breath), skin irritation and eye irritation. A standardized computer test, *NovaScan A*, was taken by the participants once a week to evaluate their work performance. *NovaScan A* is designed to test higher cognitive functions which might be applicable to jobs which involve high degrees of information processing (O'Donnell, 1992). This test consists of three specific tasks: (1) Spatial Visualization/Rotated Symbol; (2) Continuous Memory; (3) Attention Monitoring. The variable used for evaluating overall computer test score is 'thruput', which is the mean reaction time for all correct answers divided by proportion of correct answers. Higher thruput indicates poorer test scores and worse work performance.

Statistical analysis was performed using SAS (v.8.0, SAS Institute Inc., Cary, NC) statistical packages. We used mixed effect models to examine the associations between working efficiency and the predictor variables, including environmental parameters (temperature, RH, CO_2), daily work-related symptoms, demographic factors, past medical history and self-reported working conditions. The outcome variables included Task 1 (rotated symbol test) and Task 2 (continuous memory) thruput, which were log-transformed to approximate normality. To account for the correlation of repeated measurements of working efficiency (computer tests) in models, compound symmetry variance–covariance structure was assumed. Empirical (i.e. robust) standard errors were used to minimize effects of potential misspecification of the variance-covariance structure. We developed multivariate models for the effects of environmental factors and daily symptoms on working efficiency separately to avoid potential interactions between symptoms and environmental variables.

RESULTS

Among the 98 participants, 81 of them were females. Most subjects had secretarial/clerical jobs and college degrees. The distributions of age, job category, education had similar trends in both female and male subjects. Detailed information is presented elsewhere (Chao *et al.*, 2003). Numbers of weekly questionnaires and computer tests derived from each subject are summarized every 6 weeks over the sampling year (Table 1). Distributions of environmental parameters are shown in Table 2.

Table 1 Summary of numbers of weekly questionnaires and computer tests

Sampling date / Measurements	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
	5/12/97	6/23/97	8/4/97	9/15/97	10/27/97	12/8/97	1/19/98	3/2/98	4/13/98	5/25/98
# of Weekly Quest./person	4.51	3.93	3.11	3.10	3.10	3.41	3.83	3.56	3.31	–
# of Computer Tests/person	2.55	2.55	2.34	2.03	1.73	1.63	2.52	2.35	2.01	–

Six weekly questionnaires and 6 computer test results were expected to obtain from each subject every six week.

Table 2 Distribution of environmental variables

Environmental variables	Unit	Mean	SD	Median	Min.	Max.
Relative humidity	%	33.12	13.31	32.62	9.13	59.65
Temperature	°C	23.29	0.98	23.43	18.66	25.47
CO_2	PPM	689.44	184.01	670.40	379.50	1344.67

The association between environmental factors and Task 1 thruput (rotated symbol test) is shown in Table 3, controlling for number of computer tests being taken (*i*th computer test), education, types of workstation, number of people in office and sampling sites. We found higher relative humidity and temperature decreased working efficiency significantly. Similar results were found in the relationship between Task 2 thruput (continuous memory test) and environmental variables (for RH: $\beta = 0.0022$, $p = 0.0019$; for temperature: $\beta = 0.021$, $p = 0.0463$).

Table 3 Model results for rotated symbol test and environmental variables

Variables	Coefficient	SE	*p*-Value
Intercept	7.64	0.3110	0.0001
*i*th Computer test	–0.0068	0.0018	0.0001
Relative humidity	0.0017	0.0006	0.0045
Temperature	0.0164	0.0092	0.0748
Education			
High school graduate	–0.33	0.0825	0.0003
Some college	–0.65	0.0910	0.0001
College degree	–0.22	0.0604	0.0008
Graduate degree	0.00	–	–
(overall class variable)			(0.0001)
Work station			
Single person private office	–0.074	0.1101	0.4999
Shared private office	0.087	0.1001	0.3873
Open space with partitions	0.066	0.0551	0.2299
Open space without partitions	0.000	–	–
(overall class variable)			(0.0311)
Number of persons in office[a]	–0.17	0.0579	0.0029
Sampling site[b]	–	–	–
(overall class variable)			(0.0001)

[a]Number of persons in office was treated as a continuous variable and included four levels: (1) one person; (2) 2–3 persons; (3) 4–7 persons; (4) 8 or more persons.
[b]Sampling site was treated as a categorical variable.

Table 4 summarizes the correlation between daily work-related symptoms and Task 1 thruput, adjusting for other significant confounding factors. Shortness of breath and wheezing had a significant negative association with work performance. Non-specific symptom (e.g. headache, drowsiness) was not included in the final model but it had a marginal correlation with working efficiency ($\beta = 0.038$, $p = 0.0728$). Similar model results were found for task 2 thruput (for wheezing: $\beta = 0.12$, $p = 0.0002$). We did not find a significant association between past medical history and any working efficiency measures.

Table 4 Model results for rotated symbol test and daily symptoms

Variables	Coefficient	SE	p-value
Intercept	8.07	0.2231	0.0001
*i*th Computer test	–0.0071	0.0019	0.0002
Shortness of breath, wheezing	0.010	0.0311	0.0014
Education			
High school graduate	–0.30	0.0815	0.0006
Some college	–0.59	0.0998	0.0001
College degree	–0.20	0.0616	0.0019
Graduate degree	0.00	–	–
(overall class variable)			(0.0001)
Work station			
Single person private office	–0.067	0.1119	0.5476
Shared private office	0.107	0.1057	0.3104
Open space with partitions	0.059	0.0552	0.2867
Open space without partitions	0.000	–	–
(overall class variable)			(0.0560)
Number of persons in office	–0.17	0.0576	0.0028
Sampling site	–	–	–
(overall class variable)			(0.0001)

DISCUSSION

We studied the associations between indoor environmental quality and workers' perceptions of health and productivity in a longitudinal study. We used a well validated computer test to measure office workers' performance. Although the test was not a direct measure of economical effects (i.e. money gain or loss), it evaluated the variations of participants' working efficiency against their own baseline data. To limit recall bias, daily symptoms reported by the participants were used to evaluate participants' perceptions of health.

In the preliminary analysis, we found higher temperature and RH decreased office workers' performance. However, it is of note that in the study buildings, theses measurements were within the comfortable ranges most of the time (ASHRAE, 1992). Inconsistent results regarding comfort factors were observed in different studies (Sensharma *et al.*, 1998). We found work-related symptoms were associated with decreased working efficiency, similar to the findings in two other studies (Raw *et al.*, 1990; Hall *et al.*, 1991). In addition to the variables mentioned above, education, number of people in the office and types of workstation were associated with working efficiency in our study. More analysis will be performed to examine the effects of other environmental variables (i.e. bioaerosols) on working efficiency.

CONCLUSION AND IMPLICATION

In this study, we found thermal comfort factors and health symptoms were associated with working efficiency. Much remains to be studied with respect to the effects of various other environmental factors on productivity, as well as control strategies/recommendations for working efficiency improvement. A longitudinal study design and an objective measure of working efficiency are strongly recommended for future studies in order to examine the causal relationships over time.

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