AN INTERVENTION STUDY OF OUTDOOR AIR SUPPLY RATES AND SICK LEAVE AMONG OFFICE WORKERS

TA Myatt[1], J Staudenmayer[2], K Adams[1], M Walters[3], M Wand[4], S Rudnick[1], DK Milton[1*]

[1]Department of Environmental Health, Harvard School of Public Health, Boston, MA, USA
[2]Department of Mathematics and Statistics, University of Massachusetts at Amherst, Amherst, MA, USA
[3]Polaroid Corporation, Boston, MA, USA
[4]Department of Biostatistics, Harvard School of Public Health, Boston, MA, USA

ABSTRACT
We conducted an intervention study of outdoor air supply rates and sick leave among hourly office workers employed by Polaroid Corporation. High and moderately high outdoor air supply rates were specified in a random block design in two office buildings. Indoor CO_2 concentrations were measured every ten minutes. We calculated a CO_2 concentration differential by subtracting the daily average CO_2 concentration in the study area during 1-3 AM, when the building was not occupied, from the same-day average concentration between 9-5 PM. The mean weekly, workday, CO_2 concentration differential ranged from 37 to 250 ppm as compared with the ASHRAE recommended maximum differential of 700 ppm. We determined the frequency of sick leave among 294 hourly workers scheduled to work 49804.2 days in the study areas using company records. Generalized additive mixed models showed no association of CO_2 differential at the relatively low values studied and sick leave in the studied buildings.

INDEX TERMS
Productivity and economic effects, HVAC, Ventilation rates and strategies, Offices, Epidemiologic studies.

INTRODUCTION
An underutilized method of evaluating building occupant health is sick leave data. Sick leave data has been used for a variety of purposes such as to evaluate health promotion programs (Golaszewski and others 1992; Jeffery and others 1993), and to assess the efficacy of influenza vaccination (Nichol and others 1995). In general, a large fraction of sick leave is caused by respiratory illness (Bendrick 1998; Feeney and others 1998; Nichol and others 1995). Milton *et al* (Milton and others 2000) used sick leave data to identify an association between outdoor air supply rates and sick leave among office workers. The results indicated that lower levels of outdoor air supply in office buildings were associated with increased sick leave. This association was seen in both crude analyses of annual total absence and in an analysis of short-term absences. This association between ventilation and absences occurred at ventilation levels that have not often been associated with non-specific symptoms or with building related complaints (Seppanen, Fisk, and Mendell, 1999). Because of this, the authors speculated that the observed association between indoor CO_2 levels and sick leave may have been due to the increased spread of respiratory illness from either airborne spread of infection of increased susceptibility. To test this theory, we conducted an experimental intervention

* Contact author email: dmilton@hohp.harvard.edu

study of outdoor air supply rates, monitored with indoor CO_2 concentration measurements, and sick leave among hourly office workers at Polaroid Corporation.

METHODS

Study Design and Experimental Intervention

We conducted a blinded experimental intervention study to determine the effect of outdoor air supply rate, as reflected in indoor CO_2 concentrations, on sick leave absences among hourly office workers in selected areas of two office buildings. The intervention consisted of adjusting the outdoor air supply dampers to fixed positions that alternately reduced or increased the outdoor air supply, thus defeating economizer cycles and uncoupling outdoor air supply rate from seasonal variation. During each intervention cycle the ventilation level was increased in one building and decreased in the other during periods when both buildings could be studied simultaneously. Each intervention cycle lasted approximately three months. The study design was reviewed and approved by the Harvard School of Public Health Human Subjects Committee.

Office Buildings and Study Population

The office buildings used for the study were owned and occupied by Polaroid Corporation. All were located in suburban Boston, MA. All study buildings were open-plan office with cubicles and mechanically ventilated without humidification. The study buildings had an excess outside air ventilation capacity either by design or because they were remodeled from manufacturing spaces.

CO_2 Measurements

Carbon dioxide measurements in the study areas were taken once every 10 min with Vaisala monitors (model GMD20, Woburn, MA) attached to data loggers (HOBO H08-004-02, Onset Computer Corp., Bourne, MA). We calibrated each monitor with three known CO_2 concentrations covering the range of 0-1000 PPM at least once per intervention cycle. We placed at least two centrally located monitors in each study area approximately 1 m above the floor. In addition we located monitors outdoors on the roofs of study buildings.

Our primary exposure measure was the CO_2 differential above background in each building. To determine the differential, we first averaged the workday (9AM to 5PM) CO_2 concentrations and subtracted the average nighttime CO_2 concentration between 1AM - 3AM measured on the same date by the same monitor. The average CO_2 differential for the day was computed as the average across all monitors in the study area. We then averaged the daily CO_2 differentials to compute a weekly average CO_2 concentration differential above background.

Attendance Data

Hourly attendance and demographic data for the study were collected using corporate databases. The Information Technology Department provided attendance data from the payroll records for hourly employees. Workers in the hourly payroll system completed weekly time cards that contained information on hours worked and time claimed for various leave categories including sick time, vacation, and personal leave. Demographic data was provided from the Human Resources Department all-employees database. Available demographic variables included employee ID number, seniority information (start, termination, retirement dates, etc.), race, gender, age, disability, and various job and departmental classifications. Final analytic data sets were produced with one record per week per hourly employee, with demographic data appended to each record.

Data Analysis

We analyzed the relationship between CO_2 exposure in the previous week and absence in the current week using a generalized additive mixed model (Hastie and Tibshirani 1990) with a logit link. This model extends multiple logistic regression with an estimated "over-dispersion parameter" in two ways (McCullagh and Nelder 1989). First it allows the relationship between the covariates and the response to follow a smooth, not necessarily linear curve. The specific shape of the curve is modeled with a spline, a flexible model that essentially allows the data to determine the shape of the relationship. This feature of the model is necessary in our study since there is a markedly nonlinear relationship between CO_2 exposure and absence. The second way this model extends multiple logistic regression is that it accounts for the correlation within the repeated measures on individuals using individual specific random effects (McCulloch and Searle 1989). As discussed in Ruppert *et al* (Ruppert and others 2002) we estimate the parameters in this model using the pseudo-likelihood method implemented by the SAS macro GLIMMIX (Wolfinger and O'Connell 1993).

RESULTS

Study Population

Table 1. Characteristics of Study Participants

Building	1	2
Total Hourly Workers	104	190
Males (%)	64	53
White (%)	77	62
Mean Age (SD)	48.1 (9.1)	48.8 (8.0)
Total Hours Scheduled	173816.7	224616.6
Total Sick Hours	2290.0	2156.6

Building 1 was studied from November 1999 to June 2001 and Building 2 was studied from November 2000 to June 2001. A total of 294 hourly workers worked in the two buildings and were included in the study (Table 1). Although each study area had both salaried and hourly employees, only hourly employees were considered in the data analysis, because of the accuracy of records of their attendance data and because they spend the majority of their work hours in their assigned offices. The study included a total of approximately 49804 scheduled workdays and a total of 4405.6 hours of sick absence.

Environmental Measurements

Table 2. CO_2 Data

Building	1	2
Mean weekly CO_2 differential ppm (SD)	113 (55)	123 (16)
Minimum weekly CO_2 differential ppm	37	73
Maximum weekly CO_2 differential ppm	252	169

Outdoor CO_2 measurements confirmed that the indoor CO_2 concentrations returned to outdoor background concentrations each evening. CO_2 data are summarized in Table 2.

Generalized additive mixed models with logit links were fit for the individual buildings. We modeled the probability of an occupant having any absent during a week dependent on the CO_2 differential from the previous week (one-week lag). Models with no lag and two-week lags were also fit. Poisson models were also constructed with days of absence during the week as the dependent variable. The Poisson models gave fits similar to those obtained from the logistic models. Final models contained covariates for gender, race, age and individual random effects, which allow for correlation of absence rates within individuals. A smooth term for time was included

to control for unexplained trends in absence and the seasonality of absence. When the smooth term for time was not included, the shape of the curves did not change considerably, although the standard errors around the estimated curve increased substantially. Age was not significant in the models, while gender was significant in the building1 model but not the building 2 model.

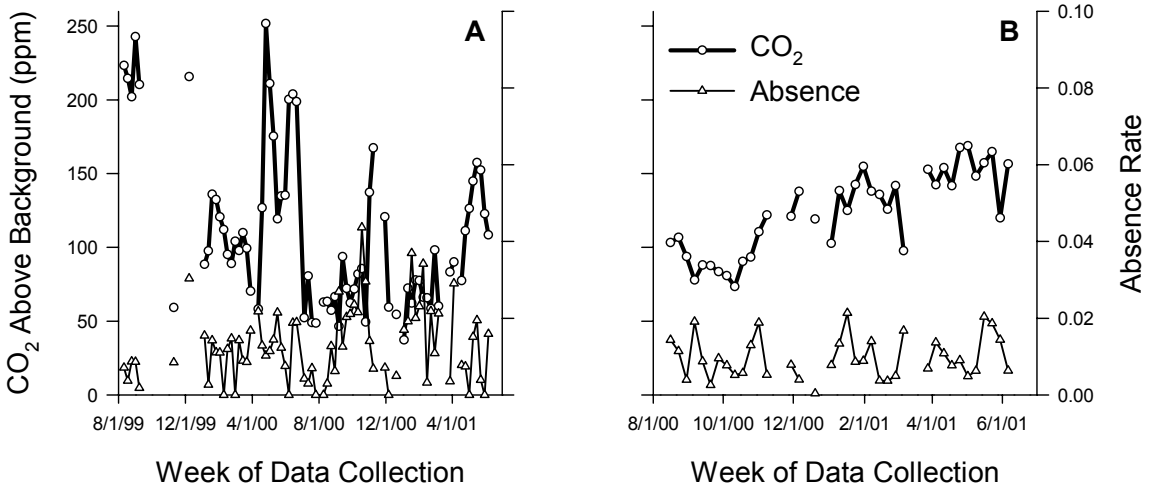
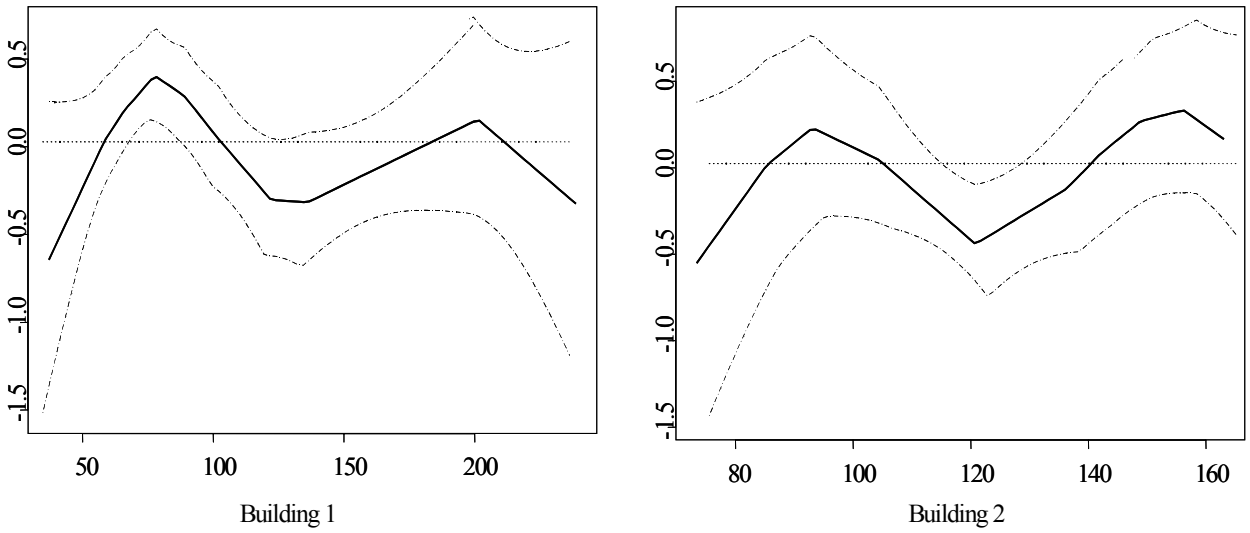


Figure 1. Weekly CO_2 concentration differential above background and weekly sick leave rates for A) Buildings 1 and B) Building 2. Data gaps reflect periods during which monitors were recalibrated and dampers were reset.



We did not observe a consistent association between CO_2 differential and absence at the levels of CO_2 under study (Figure 2). In general, portions of the fitted smooth curves are significantly different from zero if the curve and the confidence interval curves are both above or below zero. When data from the two buildings were combined, no association was observed between CO_2 concentration above background and sick-leave.

Figure 2. Contribution of CO_2, controlled for covariates, to sick leave log odds ratio is shown on the ordinate and CO_2 differential above background (ppm) is shown on the abscissa. Dashed lines show the 95% confidence intervals.

DISCUSSION

In this intervention study of sick leave absences among hourly employees at Polaroid Corp in suburban Boston, Massachusetts, we did not find a consistent positive relationship between indoor CO_2 concentrations and sick leave. This result is in contrast to the results of our earlier observational study at Polaroid Corp, which found a significant association of outdoor air supply rates and sick leave (Milton and others 2000). In the earlier study, we used a larger number of work areas (115) including areas with lower ventilation and higher CO_2 concentrations than in this intervention study. However, the previous study relied on a small number of CO_2 measurements and primarily used expert judgment, of an expert blinded to absence rates, to assign outdoor air supply rates to buildings. Thus, the intervention study was undertaken to confirm and extend the earlier findings. In the present study, we attempted to control indoor CO_2 levels by adjusting the supply of outside air supply. The buildings available for the intervention study, however, had an excess of ventilation capacity relative to the volume of office space and number of office workers. While these characteristics were advantageous for obtaining low CO_2 concentrations relative to background, it was difficult to increase the concentrations of CO_2 substantially above background. ASHRAE standards allow for 700ppm CO_2 above background in office buildings, while the maximum weekly CO_2 concentration above background in our buildings was approximately 250 ppm; the average was less than half that. We estimate (Rudnick and Milton, submitted) that below 450ppm above background, it is unlikely that rhinovirus, the most common respiratory infection in adults, would be transmitted from one office worker to another via the airborne route. Thus, it unlikely, on theoretical grounds, that we could have observed an association between CO_2 differential and sick leave due to airborne spread of respiratory infections in the office environment in the absence of an outbreak of more highly contagious agent such as influenza.

CONCLUSION AND IMPLICATIONS

This study showed that at high outdoor air supply rates sufficient to give weekly average indoor CO_2 concentrations in the rage of 50 to 200 ppm above background, the association of sick leave with decreasing outdoor air supply is inconclusive. While this result is of interest to large, highly ventilated corporate offices, it cannot be extrapolated to buildings with lower rates of outdoor air supply.

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