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Authors

Mendell, M.J.

Cozen, M.

Lei, Q.H.

et al.

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MJ Mendell¹, M Cozen, Q Lei¹, HS Brightman², CA Erdmann³,
JR Girman⁴, SE.Womble⁴

¹ Lawrence Berkeley National Laboratory
Environmental Energy Technologies Division
Indoor Environment Department
Berkeley, CA 94707, USA

² Department Of Environmental Health
Harvard School of Public Health

³ Department of Epidemiology
School of Public Health
University of Michigan

⁴ Indoor Environments Division
U.S. Environmental Protection Agency

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INDICATORS OF MOISTURE AND VENTILATION SYSTEM CONTAMINATION IN U.S. OFFICE BUILDINGS AS RISK FACTORS FOR RESPIRATORY AND MUCOUS MEMBRANE SYMPTOMS: ANALYSES OF THE EPA BASE DATA

MJ Mendell^{1*}, M Cozen, Q Lei¹, HS Brightman², CA Erdmann³, JR Girman⁴, SE. Womble⁴

¹ Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94707, USA;

² Department Of Environmental Health, Harvard School of Public Health; ³ Department of Epidemiology, School of Public Health, University of Michigan; ⁴ Indoor Environments Division, U.S. Environmental Protection Agency

ABSTRACT

Many studies have associated moisture or mold in residences with respiratory symptoms, but few studies have been conducted in office buildings. We assessed associations between moisture and ventilation system contamination and lower respiratory and mucous membrane symptoms in the U.S. EPA BASE data from 100 U.S. office buildings, using multivariate regression models. One set of models showed lower respiratory symptoms almost tripled with lack of cleaning of drip pans under air-conditioning cooling coils (odds ratio (95% confidence interval) = 2.8 (1.2-6.5)). Other models associated lack of cleaning of either drip pans or cooling coils, and water damage in mechanical rooms, with increased mucous membrane symptoms. Some moisture-related risks found by other studies were not replicated here. Overall, findings suggest that moisture or contamination in ventilation systems or occupied spaces in office buildings may have adverse health effects. Studies with more rigorous measurement of environmental factors and health outcomes are necessary.

INDEX TERMS

Moisture, Symptoms, Office workers, Ventilation systems, Indoor air quality

INTRODUCTION

A substantial body of research in residential environments has associated visible moisture and mold with upper and lower respiratory symptoms (Bornehag, Blomquist et al. 2001). Empirical evidence has long suggested that moisture and related microbiological contamination in commercial and institutional buildings such as offices are related to occupant health complaints. Only recently, however, have studies reported the association of environmental factors related to moisture and contamination in buildings or ventilation systems with increased symptoms among workers in non-industrial indoor environments (Sieber, Stayner et al. 1996; Haverinen, Husman et al. 2001; Mendell, Naco et al. 2003).

Indoor environment researchers have hypothesized that surfaces within buildings or ventilation systems, when wet and dirty for extended periods, allow growth of microorganisms that contaminate indoor air, causing allergic, irritant, or toxic health effects, especially in susceptible groups. Less frequently scheduled or ineffective inspection, cleaning, and maintenance of ventilation systems often are assumed to allow more chronic accumulation of moisture and contamination on surfaces, leading to increased risk of microbiologic growth and subsequent harmful exposures to occupants. While cleaning

* Corresponding author email: mjmendell@lbl.gov

of occupied spaces may remove accumulated contamination, wet cleaning might increase risk of microbial growth and dissemination.

Goals and hypotheses

The primary goals of this analysis were

- to investigate, in U.S. office buildings, whether building-related symptoms are associated with moisture in buildings and ventilation systems, and contamination in moist areas that may support microbiologic growth;
- to replicate, in these representative buildings, previous findings from a set of U.S. office buildings investigated for indoor air quality complaints (Mendell, Naco et al. 2003).

Our hypothesis is that certain features or practices in buildings increase the risk of moisture and contamination of potentially moist surfaces, which increase the risk of occupant exposure to microorganisms or their products with irritant, toxic, or allergic effects. Therefore, we predicted statistical associations between specific features or practices in buildings and more frequent lower respiratory and mucous membrane symptoms among occupants.

METHODS

We used the BASE data set, which was collected between 1994 and 1998 by the U.S. EPA from 100 representative U.S. office buildings and includes a variety of information on both occupants and buildings. Descriptions of this study and the available data have been reported previously (Womble, Ronca et al. 1996). Briefly, the study selected a representative set of 100 office buildings from geographic regions throughout the U.S., and then randomly selected within each building a study space with at least 50 occupants. Data on demographics, work and workspace characteristics, symptoms, and health conditions were collected in questionnaires given to all occupants in each study space who were at work on Thursday and Friday of the chosen test week. Environmental data were collected by standardized inspections of the buildings and ventilation systems and by environmental monitoring in the buildings. Facility managers were also interviewed and building plans reviewed. Each building was studied once in either summer or winter in order to maximize the possibility that heating or cooling systems would be in use during the data collection.

Outcomes used in analyses were “weekly, building-related” symptoms, based on questionnaire data and defined as specific symptoms experienced at least once per week in the last four weeks while at work and improving when away from the building. We modeled risks for two symptom group outcomes: lower respiratory symptoms (requiring at least one weekly building-related symptom from among wheezing, shortness of breath, chest tightness, and cough) and mucous membrane symptoms (requiring at least one weekly building-related symptom from among dry or itchy eyes, stuffy or runny nose, and sore or dry throat).

Independent variables used in these analyses include information from the occupant questionnaires (on demographic, health status, job, and workspace factors) and information collected by study personnel: inspection of ventilation systems, buildings, and occupied spaces; interviews with facility managers on building and ventilation system-related practices and history; and environmental monitoring for temperature, relative humidity, and ventilation.

We selected from the BASE data initial factors considered to indicate the presence of moisture, or contamination that might collect moisture, within the ventilation systems, buildings, or occupied spaces. These potential risk factors included the condition and scheduled maintenance of components in the ventilation system, current or past water damage

at specific locations in the building, and frequency of wet cleaning in indoor spaces. Variables for frequency of cleaning for drip pans and cooling coils were too highly correlated to include in the same model, so we created a summary variable that equaled the least frequent scheduled cleaning interval for either component, in each building. We also constructed additional multivariate models to estimate risks for each factor without the other.

We selected additional covariates for consideration as potential confounding variables or other potential risk factors based on prior reported findings, theoretically plausible relationships, or crude associations with outcomes in BASE data. These covariates included personal variables related to demographic, health, and job factors (sex, age, education, job satisfaction, job demand, job conflict, asthma, mold allergy, hay fever, and years working in building). Models also included variables based on environmental monitoring data related to indoor conditions in the study buildings: temperature, relative humidity, and ventilation rate.

We used a specific algorithm for selection of primary risk variables (from variables on HVAC condition and maintenance, moisture in the buildings or occupied spaces, and wet cleaning in the study spaces) and potential confounding variables (personal factors and measured indoor conditions) for initial inclusion in multivariate statistical models, and for creating of more parsimonious models. Multivariate estimates for coefficients were produced initially in multiple logistic regression models and finally in general estimating equation (GEE) logistic models adjusting for potential correlations among respondents within buildings. Multivariate-adjusted risk estimates are reported as odds ratios (ORs).

RESULTS

Data from 4,326 BASE building occupants and study spaces within 100 buildings were available for analyses. The number of workers occupying each study space during the week of BASE data collection ranged from 25 to 143, with a mean of 56. The overall response rate for the occupant questionnaire was 85%. The proportion of respondents with each of the weekly building-related symptom outcomes analyzed here was 7.9% for lower respiratory symptoms and 29.4% for mucous membrane symptoms.

Respondents to the occupant questionnaire have been described in detail elsewhere (Brightman and Moss 2000). Of respondents, 66% were female, 61% were between the ages of 30 and 49 years, and 15% were current smokers. Respondents' jobs, based on categories in the questionnaire, were: 35% professionals, 34% clerical, 17% managers, and 14% technical. Approximately 18% of respondents had a high school diploma or less, 33% had completed some college, 36% had a college degree and 18% had a graduate degree.

Table 1 presents results of the final models with the combined variable for frequency of pan and coil cleaning, with multivariate adjusted ORs and 95% CIs from GEE models for all risk factors retained in the models. A footnote in the table lists the potential risk factors not in final models. In these models, there were no statistically significant elevations in risk for weekly building-related lower respiratory symptoms, but ORs were elevated for less frequent pan or coil cleaning and past water damage in basements. For weekly building-related mucous membrane symptoms, significantly elevated ORs were associated with less frequent pan or coil cleaning and past water damage in any building mechanical room. History of fire damage in the building was associated with marginally increased risk, and current water damage in the mechanical room of the study space was significantly protective. In the alternate multivariate models containing separate variables for the cleaning frequencies of drain pans and coils (not shown), strong associations were evident for less frequent cleaning

of drain pans and building-related lower respiratory symptoms: ORs (95% CIs) were, for annual cleaning, 2.0 (1.0-3.9), and for no cleaning, 2.8 (1.2-6.5), relative to at least semi-annual cleaning. Risks for cleaning of coils were only slightly elevated. Other estimates were similar to those in Table 1.

Table 1. Multivariate adjusted^A odds ratios (ORs) and 95% confidence intervals (CIs) for associations between risk factors for moisture and HVAC contamination and two symptom outcomes, from general estimating equation logistic regression models, in the EPA BASE data collected from U.S. office buildings, 1994-1998

Covariates	Weekly Building-Related Symptom Outcomes:			
	Lower respiratory symptoms OR (95% CI)		Mucous membrane symptoms OR (95% CI)	
<i>HVAC condition and maintenance</i>				
Pan and coil cleaning frequency				
At least semi-annually	1.0	---	1.0	---
At least annually	1.5	1.0-2.5	1.3	1.0-1.6
None	1.6	0.9-2.7	1.4*	1.1-1.9
Cooling coil condition				
Clean	1.0	---	---	---
Somewhat dirty	0.8	0.5-1.1		
Very dirty	1.1	0.8-1.5		
<i>Moisture/water damage</i>				
Current water damage, study space	1.1	0.7-1.8	1.0	0.7-1.2
Current water damage, mechanical room for study space	---	---	0.6*	0.5-0.9
Current water damage, any mechanical room in building	---	---	1.1	0.6-2.0
Current water damage, basement	0.9	0.6-1.3	---	---
Current water damage, roof	0.9	0.6-1.4	0.8	0.6-1.1
Past water damage, study space	0.9	0.6-1.4	1.1	0.9-1.4
Past water damage, any mechanical room in building	---	---	1.3*	1.0-1.7
Past water damage, basement	1.3	0.9-1.7	1.0	0.9-1.2
Past water damage, roof	1.1	0.9-1.5	1.1	0.9-1.3
History of fire damage in building	1.0	0.7-1.5	1.3	1.0-1.6
<i>Wet cleaning in study spaces</i>				
Wet floor mopping frequency				
Daily	1.0	---	1.0	---
Less than daily	0.9	0.6-1.4	0.8	0.5-1.1
As needed or none	1.3	0.8-2.1	1.0	0.8-1.3

^A Models potentially adjusted (if necessary) for a set of covariates listed in text.

^B Potential risk factors eliminated include: for inadequate variability or excess missing data -- presence of air-conditioning system, presence and condition of humidifiers, and presence of air-washing systems; for excess intercorrelation or insufficient contribution in bivariate analyses -- frequency of inspection of air handlers, coils, and drain pans; past water damage in any mechanical room.

* P-value ≤ 0.05 .

DISCUSSION

As expected, infrequent cleaning of drip pans or cooling coils was associated with increased ORs for both lower respiratory and mucous membrane symptoms. This risk was especially large for drain pans that were never cleaned – almost a tripling of risk in one model for lower respiratory symptoms – although the strong correlation between cleaning frequencies of drain pans and cooling coils makes it difficult to separate the two risks. Past water damage either in basement or building mechanical rooms, and history of fire damage in buildings were associated with at least some increased risk of symptoms. Contrary to expectation, however, most water damage variables were not associated with symptoms, and current water damage in the study space mechanical room was associated with a substantial *reduction* in mucous membrane symptoms. The analysis also unexpectedly failed to find associations between symptoms and other indicators of moisture and contamination that are strongly suspected of leading to respiratory or mucous membrane health effects; for instance, cleanliness (as opposed to maintenance frequency) of drip pan, cooling coil, or outdoor air intake, identified as risks in “complaint” (Sieber, Stayner et al. 1996; Mendell, Naco et al. 2003).

The EPA BASE data provide the opportunity for the first broad, nationwide assessment, in a representative set of U.S. buildings, of the associations between suspected indoor environmental risk factors and nonspecific symptoms in office workers. The findings in this analysis of the BASE data related to moisture and presumed resulting microbial contamination are not consistently supportive of prior findings or hypothesized relationships. Findings agreed with expectations only for a small number of hypothesized relationships.

A large body of research has documented associations between evident moisture or mold in residences and respiratory health effects in residences. Some recent research has found relations between health effects and specific measurements of microbiologic growth in dust or air. In offices and other nonindustrial indoor workplaces, little research has been reported on these relationships.

Two earlier reports on a single study of office buildings in which occupants requested health investigations found many aspects of the design and maintenance of HVAC systems and buildings were associated with increased lower respiratory symptoms indicators of moisture and contamination and symptoms among building occupants (Sieber, Stayner et al. 1996; Mendell, Naco et al. 2003): e.g., air intakes near standing water, debris inside air intake, poor pan drainage, dirty ductwork, dirty filters, and general presence of moisture or lack of cleanliness in HVAC systems. Full multivariate adjustment (Mendell, Naco et al. 2003) identified debris in air intakes, poor pan drainage, and water damage in occupied spaces as significant environmental risk factors.

Limitations

It is possible that subjectively assessed factors not showing increased risk within the range occurring in the BASE “normal” buildings would be associated with risks within the NIOSH population of buildings with health complaints, because truly adverse levels of the environmental conditions of interest (e.g., substantial moisture and contamination of ventilation systems) are present in only a small proportion of the normal building population.

The BASE data, although the largest and most comprehensive collection of standardized data from representative office buildings in the U.S., was conducted primarily to obtain normative data and may have limitations for epidemiologic analyses. Subjective, self-reported health outcome assessments used are imprecise, as are environmental reports from inspection, and

this imprecision could have resulted in bias toward the null and obscured true associations. The environmental variables were collected in only 100 buildings, which allowed limited analysis of variation in these factors. Also, the many intercorrelated environmental factors assessed could often not be included in the same models, making it impossible to assess risks for some factors of interest while holding other closely related factors constant. Finally, this analysis included a large number of initial risk factors and over 35 statistical tests. Chance would predict p-values less than 0.05 for approximately two of these tests even in the absence of true associations. Thus, some of the associations found and reported here may have occurred without true underlying associations.

CONCLUSIONS AND IMPLICATIONS

These findings, although not fully consistent with prior studies, suggest that frequent cleaning of air-conditioning drain pans and coils, and general prevention and mitigation of other water incursions into buildings and HVAC systems, is advisable for prevention of building-related symptoms. These actions also should be considered in remediation efforts for complaint buildings. Finally, further research is necessary to define the scale and nature of these effects and document effective preventive measures.

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