Lack of Respiratory Improvement Following Remediation of a Water-Damaged Office Building

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Background *Damp buildings are commonly remediated without removing employees or ongoing medical surveillance.*

Methods *We examined paired pulmonary function and questionnaire data from 2002 and 2005 for 97 employees in a water-damaged building during ongoing but incomplete remediation.*

Results *We observed no overall improvement in respiratory health, as reflected in symptom scores, overall medication use, spirometry abnormalities, or sick leave. Four employees went from borderline bronchial hyperresponsiveness to bronchial hyperresponsiveness; six developed abnormal spirometry; three more reported post-occupancy current asthma, and four hypersensitivity pneumonitis. The number of participants without lower respiratory symptoms decreased from 27 in 2002 to 20 in 2005. Respiratory cases relocated in the building had a decrease in medication use and sick leave in 2005.*

Conclusions *During dampness remediation, relocation may be health protective and prevent incident building-related respiratory cases. Without relocation of entire workforces, medical surveillance is advisable for secondary prevention of existing building-related disease.* Am. J. Ind. Med. *© 2010 Wiley-Liss, Inc.*

KEY WORDS: dampness; asthma; hypersensitivity pneumonitis; healthy worker effect; building-related illness

INTRODUCTION

In 2001 the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation of a 20-story office building, which was known to have recurrent water damage since occupancy by its current tenants in 1994 [Cox-Ganser et al., 2005; Park et al., 2006, 2008]. Prior to 2001, environmental surveys by several consultants revealed water incursion through the roof, around windows, and under sliding doors from balconies, with exacerbation of water intrusion through the building envelope by a negative pressure gradient indoors compared to outdoors. In addition, plumbing leaks had damaged interior walls. From 1995 to July 2001, 60 employees filed workers' compensation claims for building-related health conditions.

During our 2001 questionnaire survey, we found that the incidence of adult-onset asthma among participating office workers was 7.5 times higher after building occupancy than prior to occupancy [Cox-Ganser et al., 2005]. NIOSH investigators found statistically significant increased prevalence ratios for wheezing (2.5), lifetime asthma (2.2), current asthma (2.4), adult-onset asthma (3.3), and respiratory symptoms improving away from work (3.4) when compared with the U.S. adult population. We identified a five-person cluster of cases with post-occupancy physician-diagnosed hypersensitivity pneumonitits and three cases of physician-diagnosed post-occupancy sarcoidosis [Cox-Ganser et al., 2005]. An exposure–response relationship existed between

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fungal concentrations in vacuumed dust and both lower respiratory symptoms (LRS) and physician-diagnosed post-occupancy asthma [Park et al., 2006, 2008].

The owner of the building completed many internal and external repairs between 2000 and April 2004. From 2000 to 2002, cubicle partitions and carpets were cleaned, water-stained wallboard and carpet replaced, wallpaper and underlying mold removed from bathrooms, and heating, ventilating, and air conditioning high-efficiency filters added. Exterior remediation included repairs to roof copings and caulking brick. In early 2004, the planned repairs of building envelope, sheetrock, and roof replacement were completed, at an expense of 7.5 million dollars. In 2004, an environmental management system was installed for control of mechanical systems. The absence of a vapor barrier under the brick cladding was not addressed. Environmental sampling in 2002 and 2005 documented that the average proportion of hydrophilic fungi in relation to total fungi in vacuumed floor dusts at several hundred work stations in the building decreased in 2005 compared to 2002 measurements. However, consultants documented continuing water intrusion through the building envelope in 2005 and later, necessitating ongoing repair of caulking and building envelope and sheetrock removal. Thus, planned remediation failed to prevent ongoing dampness.

Our objectives were to examine if the respiratory health of occupants improved from (1) incomplete building remediation to address water damage and (2) relocation within the building during the remediation period. We evaluate the effectiveness of these interventions with paired data from respiratory questionnaires and lung function tests for a non-representative subset of office workers in the building tested in both 2002 and 2005. In order to examine healthy worker survival effect in the context of a damp building, we also examine differences in the 2002 health characteristics between those who stayed and those who left employment between the 2002 and 2005 surveys.

METHODS

Remediation Intervention

Remediation was building-wide and was not targeted to floors or workstations of affected occupants, who existed on every floor. We did not have a sufficient number of workstation environmental measurements over time for persons who had medical testing in both 2002 and 2005 to examine the association between occupants' health and their microenvironments.

Relocation Intervention

An aggressive medical management program was instituted in 2000 in response to the high rate of respiratory illness among occupants. Initially, a limited number of the sickest employees were moved into nearby buildings, with objective health improvements (Lin et al., 2005, unpublished report, available upon request, NIOSH reference # 000HCCA7-2004-11836). Some of the sick employees were relocated for medical reasons within the building, in the hope that their respiratory health might improve on a floor with a lesser degree of water damage or different time course of remediation. Subsequently, some participants were relocated for administrative reasons, for example, to be closer to their working groups.

Study Population

The study population was 97 office workers who participated in both cross-sectional surveys in June 2002 and August 2005. We used these paired data to assess interval changes in health indices over a 3-year period of remediation efforts. We compared the 97 participants to the remainder of 2002 study subjects who were not followed in 2005, some of whom had left employment (Group B1; N = 56) and some of whom chose not to participate in 2005 (Group B2; N = 95). These 2002 groups were not representative of the building occupants overall because 2002 participants were selected to characterize one group meeting a case definition of possible building-related lower respiratory disease (case group) and a comparison group who had no lower respiratory or systemic symptoms or diagnoses reported in an earlier questionnaire in 2001 [Cox-Ganser et al., 2005]. We defined respiratory cases as those reporting at least three of five LRS (wheeze, chest tightness, attacks of shortness of breath, coughing attack, or awakened with an attack of breathing difficulty) occurring weekly over the past month; or at least two of three symptoms consistent with hypersensitivity pneumonitis (HP) (fever and chills, flu-like achiness or achy joints, or shortness of breath when hurrying on level ground or walking up a slight hill) occurring weekly over the past month; or current asthma with post-occupancy physician diagnosis; or physician-diagnosed HP or sarcoidosis. By 2002, portions of the case and comparison groups had changed health status. For the present analyses, we categorized the 97 participants as respiratory cases and non-cases (not meeting the case definition). All participants provided written informed consent, approved by the NIOSH Human Subjects Review Board, in both 2002 and 2005.

Health Symptoms Questionnaires

The 2002 and 2005 health questionnaires contained identical sections on demographics; upper and lower respiratory and systemic symptoms in the last 4 weeks and 12 months, and in relation to being in the building; sick leave days due to respiratory conditions in the last 12 months; breathing medication use in the last 4 weeks and 12 months;

physician diagnoses of asthma and HP along with dates of diagnoses; asthma emergency room visits; smoking history; and work history in the building.

We defined LRS as wheeze/whistling in the chest, chest tightness, shortness of breath, and cough occurring in the last 4 weeks. We constructed a LRS point scale as the frequency and number of LRS occurring in the last 4 weeks, with a possible range from 0 to 16. We defined work-related LRS as symptoms occurring at least two to three times a week in the last 4 weeks and reported to improve away from work. Systemic symptoms were defined as the presence of fever, chills, night-sweats, flu-like achiness, or unusual tiredness or fatigue that occurred weekly or daily in the last 4 weeks. We defined post-occupancy current asthma as asthma reported as diagnosed by a physician and still present, with a date of diagnosis at or after occupancy in the building. We defined medication use with a point scale based on respiratory oral, inhaler, or non-prescription medications, with a possible range from 0 to 24. This medication scale did not include antihistamines for upper respiratory complaints.

Medical Tests

Pulmonary function testing in 2005 was identical in procedures to 2002 testing [Cox-Ganser et al., 2005]. In brief, we measured forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV_1) using a volume spirometer (SensorMedics Spirometer, Yorba Linda, CA) and calculated the FEV_1 to FVC ratio. We defined an abnormal test result as being at or below the lower limit of normal [Hankinson et al., 1999], and we characterized abnormal test results as having patterns of restriction, obstruction, or both [American Thoracic Society, 1995]. To detect bronchial hyperresponsiveness (BHR), we performed methacholine challenge testing using standardized techniques [Crapo et al., 2000] with 0.125, 0.5, 2, 8, and 32 mg/ml methacholine. We calculated the provocative concentration of methacholine that causes an interpolated 20% decline in FEV_1 from the baseline (PC_{20}). We defined BHR as a PC_{20} of $\leq$4.0 mg/ml and borderline BHR as a PC_{20} between 4.1 and 16.0 mg/ml [Crapo et al., 2000]. In subjects with baseline $FEV_1 < 70\%$ of the predicted value, we tested for reversible bronchoconstriction with a bronchodilator, using a criterion of a 200 ml and 12% increase in FEV_1.

Data Analysis

To assess the possibility that our study participants might reflect a healthy worker survivor effect, we compared health characteristics between participants (Group A) versus those who left employment (Group B1) and the non-participants who stayed in the building (Group B2). We tested for differences in 2002 health status between participants and non-participants by using non-parametric Wilcoxon rank-sum analyses for the continuous variables and chi-square tests for the categorical variables.

To assess the effect of the remediation intervention on respiratory health, we examined 2002 and 2005 questionnaire and pulmonary test data for the 97 persons in the cohort, as well as by the 2002 subgroups of respiratory cases and non-cases. To assess the effect of relocation within the building, we compared paired results from 2002 and 2005 for the relocated group of respiratory cases and the non-relocated respiratory cases.

We used SAS® software (version 9.2, SAS Institute, Inc., Cary, NC) to analyze the data. We used a probability level of $P \leq 0.05$ as a criterion of statistical significance, and $0.05 < P \leq 0.10$ as being marginally significant. To examine time trends, we compared 2002 and 2005 results using paired *t*-tests for continuous variables and McNemar's test for categorical variables. We used SAS® PROC MIXED to examine time trends between respiratory cases and non-cases for continuous variables and SAS® PROC GENMOD for categorical variables. We also used these procedures to study the effect of relocation for respiratory cases. The categorical variables included cases of abnormal spirometry, BHR, breathing medication use, and physician-diagnosed post-occupancy current asthma. The continuous variables included mean changes in the spirometry results (% predicted FVC, % predicted FEV_1, FVC/FEV_1 ratio), sick leave days, and point scales for LRS and medication use.

RESULTS

Characteristics of Study Cohort

The 97 participants had worked in the building for an average of 6.8 years (range: 0.7–8.0 years) in 2002; had a mean age of 47.0 years; and were 64% female (Table I). Most were never smokers (67%). In 2002, 54 (56%) were classified as respiratory cases and the remaining 43 as non-cases. In 2005, 51 (53%) were classified as respiratory cases. Many of the non-cases, while not meeting the respiratory case definition by frequency and number of symptoms or physician diagnoses, had symptoms in 2002: over one-third (16/43) had LRS, 21% (9/43) had systemic symptoms, and only about one-half had no lower or systemic symptoms (53%). Of the 97 participants, 81 participated in spirometry testing and 63 had methacholine challenge or bronchodilator testing in both 2002 and 2005.

Those 2002 participants who had left employment were significantly older and more likely to have ever smoked (never smokers, 48%) when compared to cohort study participants (Table I). They did not differ significantly from participants in building tenure or gender. They had a significantly lower mean percent predicted FVC. In addition, many of their other indices of respiratory health were worse, although not significantly so.

TABLE I. June 2002 Characteristics of Participants and Non-Participants

Characteristic	Participants (A) n = 97	Non-participants (B), n = 151 Left employment (B1), n = 56	Continued employment (B2), n = 95
Age in years, mean (SD)	47.0 (7.2)	**50.2** (**9.9**)**	**44.9** (**8.0**)*
White race, % (n)**	78% (76)	71% (40)	**63**% (**60**)**
Never smokers, % (n)	67% (65)	**48**% (**27**)**	65% (62)
Respiratory case, % (n)	56% (54)	61% (34)	56% (53)
Bronchial hyperresponsiveness or positive bronchodilator test, % (n)	2.5% (2)	9% (4)	8% (6)
FVC, % predicted	98%	**91**%**	98%
FEV_1, % predicted	96%	90%	97%
FEV_1/FVC ratio	79%	78%	79%
Abnormal spirometry, % (n)	12% (12)	21% (11)	17% (15)
Obstructed or mixed, % (n)	8% (8)	9% (5)	12% (10)
Restriction, % (n)	4% (4)	11% (6)	6% (5)
LRS point scale, mean (SD)	3.6 (3.7)	4.2 (4.2)	4.7 (4.6)
Work-related LRS, % (n)	32% (31)	41% (23)	38% (36)
Medication use scale, mean (SD)	1.0 (2.2)	1.8 (3.9)	1.2 (2.4)
Oral steroid use (last 12 months), % (n)	14% (14)	18% (10)	12% (11)
Inhaled steroid use (last 4 weeks), % (n)	9% (9)	16% (9)	11% (10)
Beta-agonist use (last 4 weeks), % (n)	12% (12)	16% (9)	20% (19)
Post-occupancy current asthma, % (n)	19% (18)	20% (11)	18% (17)
Sick leave days (respiratory), mean (SD)	3.8 (7.9)	7.9 (17.0)	3.6 (6.6)

LRS, lower respiratory symptoms.
The 2005 non-participants (Group B) were divided in two groups: those who left employment after 2002 (B1), and those who chose not to participate (B2).
Bold denotes marginal or significant difference between Group A with either Group B1 or Group B2.
*$P \leq 0.10$.
**$P \leq 0.05$.

Interval Changes in Health After Remediation Intervention

Most indices of respiratory morbidity were not statistically different for the 97 participants in 2002 and 2005, with the exception of a significantly lower FEV_1/FVC ratio (78.5% in 2002 vs. 77.3% in 2005, $P < 0.05$), increase in BHR (0% in 2002 vs. 6.3% in 2005, $P < 0.05$), and decreased prevalence of oral steroid use in the last 12 months (14.4% vs. 4.1%, $P < 0.05$). The percentage of abnormal spirometry was higher in 2005, although not significantly so (16% in 2005 vs. 10% in 2002, $P = 0.06$). Indices not significantly changed for the entire group were the percent predicted FEV_1 and FVC, LRS point and medication use scales, prevalence of inhaled corticosteroid use in the last 4 weeks, beta-agonist use in the last 4 weeks, and respiratory sick leave days. However, these stable health indices for the cohort obscure that three more persons had a physician diagnosis of post-occupancy current asthma and four persons were diagnosed with HP in the 3-year interval.

The dynamics of physician-diagnosed respiratory disease included some persons reporting no longer having asthma and others developing it. In 2002, there were 18 cases (18.6%) of post-occupancy current asthma among the 97 participants. In 2005, 3 of the 18 reported no longer having current asthma. One of these employees had been relocated to a different building and upon return to the study building in 2003 was relocated to a new floor. Of the remaining 15 employees with post-occupancy current asthma, 4 had been relocated within the building, each of whom had decreased use of medications in 2005. In 2005, three participants reported post-occupancy current asthma that did not report it in 2002. These employees had reported LRS in 2002 and all were classified as respiratory cases on the basis of symptom number and frequency. Two increased medication usage and two also reported visiting a doctor's office, urgent care facility, or emergency department in the last 12 months for an acute asthma attack in 2005.

Four participants reported newly diagnosed HP in 2005, with two having onsets in 2002, one in 2003, and one in 2004. One had no lower respiratory or systemic symptoms but had borderline BHR in 2002 which became abnormal in 2005. The other three had been classified as respiratory cases in 2002, with two reporting an asthma diagnosis as well in the

2005 survey. Among the four cases, the range of respiratory sick leave varied widely (range: 4–110 days). One of the cases had relocated within the building. None reported home dampness.

Medical test results were also dynamic. In 2002, two participants had BHR, but no test results were available for these people in 2005. Four employees with borderline BHR in 2002 developed BHR in 2005. Of the eight employees with abnormal spirometry results in 2002 that also had 2005 results available, one person with mild obstruction had normal spirometry in 2005. Three participants developed obstruction and three participants developed restriction in 2005. In summary, the number of employees in the cohort who had abnormal pulmonary function tests increased from 8 in 2002 to 13 in 2005.

Interval Changes in Health by Respiratory Case Status

Both respiratory case and non-case groups in the 2002 cohort changed little over the 3-year interval (Table II). As a group, respiratory cases used less oral steroids in 2005. Nine of the 54 respiratory cases improved such that they no longer met the case definition in 2005, while six 2002 non-cases met the respiratory case definition by 2005. There were no significant differences in the time interval change for health outcomes between the respiratory case and non-case groups, with the exception of abnormal spirometry which increased in the non-case group (0–11%) but stayed relatively stable for the respiratory case group. Among the 2002 non-case group, the number of persons without LRS shrank from 27 in 2002 to 20 in 2005. Among the newly symptomatic was one new HP case. The 2002 non-case group as a whole had a significant decrease in mean FEV_1/FVC ratio in 2005 (Table II).

When we stratified the entire cohort (both respiratory cases and non-cases) by use of breathing medication, persons who did not take any breathing medication in 2002 had a significant decrease in mean FEV_1/FVC ratio and increase in medication use in 2005 ($P < 0.05$). They also were more likely to have abnormal spirometry, BHR, or LRS in 2005 ($P < 0.10$). Those that did take medication in 2002 took significantly less in 2005, including a large decrease in the use of oral steroids (data not shown).

Interval Health Effects of Relocation Intervention

There were three persons that relocated from an outside building back to the building between the 2002 and 2005 surveys. One person who returned to the building in 2004 was diagnosed with HP that same year. This person had a worsened health status after returning to the building, as indicated by breathing medication use and LRS in the 2005

TABLE II. Mean Change in Health Characteristics From 2002 to 2005 Among Surveys Participants by 2002 Group Assignment (Respiratory Cases, Non-Cases) Using Only Paired Data

	Respiratory cases (2002, N = 54)		**Non-cases (2002, N = 43)**	
Health characteristic	**2002**	**2005**	**2002**	**2005**
Bronchial hyperresponsiveness or positive bronchodilator test, % (n)	0	6.7% (2)	0	6.1% (2)
FVC % predicted	96.1%	95.5%	100.8%	101.9%
FEV_1 % predicted	93.6%	92.7%	99.9%	99.7%
FEV_1/FVC ratio	**78.1**%*	**77.2**%*	**79.0**%**	**77.4**%**
Abnormal spirometry, % (n)*	18% (8)	20% (9)	**0****	**11**% (**4**)**
LRS point scale, mean (SD)	5.7 (3.6)	5.7 (3.8)	**0.9** (**1.4**)*	**1.5** (**2.4**)*
Work-related LRS, % (n)	51.9% (28)	50.0% (27)	7.1% (3)	16.7% (7)
Medication use scale, mean (SD)	1.7 (2.8)	1.1 (2.1)	0.2 (0.7)	0.3 (1.2)
Oral steroid use (last 12 months), % (n)	**22.2**% (**12**)**	**7.4**% (**4**)**	4.7% (2)	0
Inhaled steroid use (last 4 weeks), % (n)	14.8% (8)	13.0% (7)	2.3% (1)	2.3% (1)
Beta-agonist use (last 4 weeks), % (n)	22.2% (12)	22.2% (12)	0	7.0% (3)
Post-occupancy current asthma, % (n)	33.3% (18)	37.0% (20)	0	2.3% (1)
Sick leave days (respiratory), mean (SD)	4.6 (6.4)[a]	6.3 (15.6)[b]	2.9 (9.6)[c]	2.0 (5.7)[d]

LRS, lower respiratory symptoms.
In bold: Health characteristic for which group (case vs. non-case) effect in individual interval changes from 2002 to 2005 was significant (health characteristic bolded); or the change from 2002 to 2005 within a group was significant (value bolded). Results after excluding an outlier who missed 110 days due to respiratory symptoms in 2005 are given as: [a]4.2 (5.6), [b]4.3 (6.2). Results after excluding an outlier who missed 60 days due to respiratory symptoms in 2002 are given as: [c]1.5 (3.2), [d]1.6 (5.0). Due to small numbers, we were unable to conduct significance testing for time interval change between cases and non-cases on oral steroid use, beta-agonist use, and post-occupancy current asthma.
*$P \leq 0.10$.
**$P \leq 0.05$.

survey. The other two persons' health status remained relatively stable after moving back to the building.

Thirteen participants were relocated to another floor within the building between 2002 and 2005, of which 10 were respiratory cases. Relocated respiratory cases had a significant decrease in their medication use scale, with a decrease in use of any breathing medication from 60% to 20%, accounted for by decreasing bronchodilator use and elimination of use of oral steroids in the previous year and inhaled steroids in the last 4 weeks (Table III). However, relocated respiratory cases also showed signs of significantly decreased lung function from 2002 to 2005. In contrast, respiratory cases that were not relocated showed no significant change in medication usage. Non-relocated cases resembled non-relocated non-cases in showing little and non-significant change in health characteristics from 2002 to 2005. However, non-relocated non-cases did show a significant decrease in mean percent predicted FEV_1/FVC, and most notably, four persons with normal spirometry in 2002 had abnormal spirometry in 2005. None of the three relocated non-cases changed health status.

DISCUSSION

Our 3-year follow-up of a 97-person cohort in a water-damaged office building found that substantial remediation did not result in an overall improvement of their respiratory health. As a group, respiratory cases stayed sick and did not show substantial improvement in their health status, with the exception of less oral steroid use in 2005. New illness occurred among 2002 non-cases, with a significantly increased proportion developing abnormal spirometry. The change in case status was similar between the respiratory and non-case groups, with 14% of the non-cases becoming respiratory cases and 17% of the respiratory cases becoming non-cases in 2005. Altogether, the three new cases of asthma and four new cases of HP among 97 persons are sentinel events reflecting continuing hazards associated with this office building. Indeed, we noted a similar ongoing risk in this building between a 2001 survey and the 2002 survey, in which 55% of a group without respiratory symptoms developed them in a 9-month interval, with 17% achieving respiratory case status [Cox-Ganser et al., 2005]. Ongoing incidence of new physician-diagnosed lung disease, in combination with incident respiratory symptoms from 2001 to 2002 and with a 7.5-fold excess incidence of asthma in this building from occupancy until 2001 [Cox-Ganser et al., 2005], are all consistent in documenting a continuing hazard since building occupancy in 1994. In fact, three incident cases of physician-diagnosed asthma among the 79 cohort members who did not have this diagnosis in

TABLE III. Mean Change in Health Characteristics Among Respiratory Cases and Non-Cases by Relocation Status From 2002 to 2005

	Respiratory cases (N = 54)[†]				Non-cases (N = 43)	
	Relocated (N = 10)		Non-relocated (N = 42)		Non-relocated (N = 39)	
Health characteristic	**2002**	**2005**	**2002**	**2005**	**2002**	**2005**
Bronchial hyperresponsiveness or positive bronchodilator test, % (n)	0	0	0	9.1% (2)	0	3.4% (1)
FVC % predicted	**97.5**%**	**94.3**%**	95.4%	95.4%	100.8%	102.2%
FEV_1 % predicted	**96.1**%*	**92.9**%*	93.1%	92.7%	99.8%	99.4%
FEV_1/FVC ratio	**79.4**%**	**78.3**%**	78.2%	77.3%	**79.0**%**	**77.0**%**
Abnormal spirometry, % (n)	10% (1)	10% (1)	18% (6)	21% (7)	**0****	**12**% (**4**)**
LRS point scale, mean (SD)	4.0 (2.4)	4.6 (3.2)	6.1 (3.7)	5.9 (4.0)	0.8 (1.3)	1.3 (2.2)
Work-related LRS, % (n)	50% (5)	70% (7)	52% (22)	48% (20)	8% (3)	13% (5)
Medication use scale, mean (SD)*	**2.5** (**3.2**)**	**0.4** (**1.0**)**	1.5 (2.7)	1.2 (2.2)	0.2 (0.7)	0.03 (0.2)
Oral steroid use (last 12 months), % (n)	**30**% (**3**)*	**0***	21% (9)	10% (4)	3% (1)	0
Inhaled corticosteroid use (last 4 weeks), % (n)	20% (2)	0	12% (5)	14% (6)	3% (1)	0
Beta-agonist use (last 4 weeks), % (n)**	**50**% (**5**)*	**20**% (**2**)*	14% (6)	21% (9)	0	3% (1)
Post-occupancy current asthma, % (n)	50% (5)	50% (5)	31% (13)	36% (15)	0	0
Sick leave days (respiratory), mean (SD)	3.3 (4.8)	1.9 (2.6)	4.8 (6.8)[a]	7.6 (17.5)[b]	1.2 (2.4)	1.6 (5.1)

LRS, lower respiratory symptoms.
In bold: Health characteristic for which effect of relocation on individual interval changes from 2002 to 2005 was significant for respiratory cases (health characteristic bolded); or the change from 2002 to 2005 within a group (paired analysis) was significant (value bolded). Comparisons were not made between cases and non-cases.
Results after excluding an outlier who missed 110 days due to respiratory symptoms in 2005 are given as: [a]4.2 (5.8), [b]5.1 (6.8).
Due to small numbers, we were unable to conduct significance testing for time interval change between relocated and non-relocated cases on bronchial hyperresponsiveness or positive bronchodilator test, inhaled corticosteroid use, and oral steroid use.
*$P \leq 0.10$.
**$P \leq 0.05$.
[†]Two cases were excluded from the analysis that relocated back to the building from another site.

2002 suggests that the incidence ratio for asthma is about 6.7 times expected over the 3-year remediation interval, in comparison to an expected incidence of about 1.9 per 1,000 person-years. Objective measures of paired pulmonary function and BHR tests substantiated deteriorating overall health status, as indicated by an overall decrease in FEV_1/FVC and new BHR in four persons. No objective pulmonary function measure documented significant improvement in this population. Although lack of improvement might be due to insufficient time for improvement in building-related lung disease, this interpretation is undermined by the occurrence of new disease, implying continuing hazard.

The four new cases of HP reported since the initial survey in 2002 resulted in a cumulative prevalence of nine cases among 248 participants (3.6%), with the possibility that additional incident cases occurred in the non-participating workers. This prevalence is not unusual among occupants of buildings in which HP cases have been recognized. Environmental scientists have not compared environmental exposure characteristics in damp buildings with and without HP cases. A sentinel case of HP usually is accompanied by building-related asthma cases and high prevalences of respiratory symptoms among co-workers, suggesting an overlap of health outcomes with dampness-associated exposures. None of the participants with incident diagnoses of HP reported home dampness or bird exposures as alternative environmental causes.

Despite the expenditure of 7.5 million dollars by 2004, the intended improvement in occupant health did not occur for all of the 97 employees. There are at least three possible explanations that merit consideration. First, is it possible that the increased respiratory morbidity among these building occupants was not related to dampness-related exposures and hence not likely to be affected by dampness remediation? A number of observations make this unlikely. The building occupants in 2001 reported asthma onsets before building occupancy that resulted in a normal incidence rate during adulthood; this rate increased 7.5-fold after occupancy until 2001 and continues in this small cohort at a similar rate from 2002 until 2005. HP is a rare disease, and the clusters in this building both before 2002 and between 2002 and 2005 suggest a common cause from continued dampness-related exposures. The temporal occurrence of respiratory symptoms in relation to the work day suggests building-related causative exposures. The improvement of a subset of respiratory cases with relocation outside the building and within it suggests a causal association with building-related exposures. The correlation of objective measurements with case and non-case status based on symptoms minimizes any psychological explanation for this morbidity, which in any case does not meet diagnostic criteria for mass psychogenic illness in its symptoms, lack of a chain of transmission, and endemicity over many years.

Second, is it possible that remediation was adequate but occupants with respiratory illness might not improve? Indeed there is considerable information in the literature that suggests that recovery from damp building-related respiratory illness is incomplete and delayed. Patovirta et al. [2004] did not find respiratory symptom improvements 1 year after remediation, nor did Jarvis and Morey [2001] 4 months after occupants were relocated to a dry building. The latter investigators did document cross-sectional improvements in chest tightness, shortness of breath, and cough approximately 4 years later before re-occupancy of the remediated building. However, the prevalences of those symptoms, as well as wheezing, were still double the prevalences found in the comparison population. Haverinen-Shaughnessy et al. [2004] demonstrated that post-remediation prevalence of respiratory symptoms decreased in students studied cross-sectionally in schools followed up to 5 years after repairs, but that students participating in all three surveys after remediation showed no improvement. This suggests that affected persons may not improve post-remediation, but new entrants to a remediated building may avoid the previous respiratory risks that students demonstrated before remediation. In our cohort study, all participants had been exposed to building conditions over the remediation period, and their experience is consistent with lack of improvement over time.

Third, is it possible that the lack of improvement in respiratory health is attributable to inadequate remediation? With the economic infeasibility of attending to the building envelope's vapor barrier, the continued water intrusion documented by consultants was not surprising. Tools to assess remediation adequacy are evolving with building science and have been hampered by the dearth of environmental measurements that correlate with health outcomes across many investigations. In this building, indications of lower proportions of hydrophilic fungi in 2005 suggested some environmental effect of remediation (data not shown), but observational indices of dampness remain a robust predictor of building-related respiratory effects [Park et al., 2004; Cox-Ganser et al., 2009]. Some investigators have reported that microbial concentrations are high during repair processes or after partial remediation [Rautiala et al., 1998; Patovirta et al., 2004; Lignell et al., 2007]. It is possible that renovation activities increase exposures associated with water damage through insufficient containment. Other researchers have also found that incomplete remediation does not lower the burden of respiratory disease [Haverinen-Shaughnessy et al., 2004, 2008; Patovirta et al., 2004; Meklin et al., 2005; Lignell et al., 2007]. For example, Haverinen-Shaughnessy et al. [2008] reported that health status of occupants of a school building remained similar or even deteriorated over a 3-year period of remediation. Our study adds to the literature that partial remediation is ineffective in curbing building-related respiratory disease, at least among occupants present in the building prior to remediation efforts, some of whom developed new illness during the remediation period.

The only subset of our cohort that had some improvement in their health status was the relocated respiratory case group, as shown by the significant decrease in medication use, although they also had a small decrease in their lung function values. This decrease in lung function may have been the result of decreasing or eliminating breathing medications in 2005. The mean number of sick leave days also decreased in 2005, from 3.3 to 1.9 days. In contrast, the non-relocated respiratory cases did not change significantly between 2002 and 2005. In other studies, relocation of damp building occupants to dry buildings has improved respiratory symptoms and other health indices [Bourbeau et al., 1996; Sudakin, 1998; Jarvis and Morey, 2001]. In this 20-story building with ongoing remediation over the 3-year period, microenvironments certainly were likely, both because of varying initial and recurrent water infiltration by floor and remediation proceeding in different locations at different times.

Although the expenditure of great sums of money in this building did not have its intended effects on either dampness or health, this building is far from unique, as suggested by the literature on health effects and partial remediation above. Thus, primary prevention of dampness in buildings is critical. This consists of proper building siting, design, construction, commissioning, and maintenance that minimize dampness [OSHA, 2006]. Few buildings are vacated for remediation efforts. Insofar as morbidity associated with building-related respiratory disease may be permanent in some individuals, prevention of additional cases occurring during remediation is an important public health responsibility. In buildings with design and structural deficits that make successful remediation of water damage unlikely or prolonged, relocation of all occupants should be considered to protect occupant health. In this building, medical surveillance with repeat surveys provided the data with which to make such public health decisions. If relocation is not feasible, regular medical surveillance can assist secondary prevention of building-related lung disease by identifying occupants whose deteriorating health might benefit by medical restriction from the building or relocation away from renovation work or to a dryer portion of the building. Physicians caring for employees with likely building-related respiratory illness might be prudent to advise such changes in work environments in an effort to prevent asthma from becoming chronic and irreversible.

The extreme in relocation is leaving employment. Our 97-person cohort did not include those who left employment after the 2002 survey, and we had no follow-up on those who left. However, it is of interest that the 56 persons who left employment appeared to be sicker on average in 2002 than those who remained in the building. They were more likely to have ever smoked cigarettes, their percent predicted FVC was significantly lower, and other health indices appeared to be worse, although not significantly so. This is evidence of the healthy worker survival effect, in which sicker employees leave employment or relocate [Eisen, 1995; Chen and Seaton, 1996; Le Moual et al., 2008]. In fact, investigators were aware of a number of ill workers who retired or sought medical disability by 2005. In a previous analysis conducted in 2005 (data not shown), we identified persons who had left employment after the initial questionnaire survey in 2001. We found that 32% of persons that had met the respiratory case definition in 2001 had left the building, compared to only 17% who did not have any of these symptoms or diagnoses. Accordingly, our healthier participant group is not representative of the building employees, either in 2002 or 2005. The implication of the healthy worker survival effect is that the burden of building-related lung disease in this office building was probably underestimated in our previous publication [Cox-Ganser et al., 2005]. In the present cohort study, however, lack of representativeness is not a bias affecting interpretation, since participants are compared to themselves at two points in time. Since sicker workers tended to leave employment, we are unable to characterize the natural history of an important segment of the population affected by this building environment.

A major limitation of the study is the lack of individual exposure data with which to assess interval changes in work station environments as a measure of effectiveness of environmental remediation. Measurements of biomass are inconsistently related to risk of respiratory disease in damp environments. In this building, however, some dust indices, such as levels of culturable fungi, ergosterol, and endotoxin in dust, were associated with health outcomes in 2002 [Park et al., 2006, 2008]. It would have been of interest to measure paired health outcomes by such environmental measurements at workstations. But in the setting of continued water incursion in the building, we did not have the opportunity to study effective remediation anyway. An alternative to get at individual exposure response would have been to query participants about their own observations of dampness at their workstations, but these queries were not made in our questionnaire.

Major strengths of this article are that deterioration of health was supported by objective pulmonary function measurements, the cohort approach to assessment of changing health status among participants, and baseline characterization of non-respondents, including those who left employment. Since many buildings are subject to ongoing water damage and ongoing remediation of dampness, our follow-up of building occupants suggests the importance of medical surveillance in such buildings for the purposes of supporting approaches for primary and secondary prevention of building-related lung disease. Early identification of building characteristics that require prolonged remediation or which make successful remediation economically infeasible is important for protecting occupant respiratory health and curbing remediation expenditures. Identification of respiratory health outcomes should prompt consideration of relocating all employees to prevent incident cases during remediation. Above all, primary prevention of dampness in office buildings is critical, as ongoing remediation appears to have been of no meaningful benefit for this particular cohort.

In conclusion, the present study contributes to the evolving literature on health-related effectiveness of ongoing remediation in water-damaged buildings. We found no overall change in respiratory health and pulmonary function from 2002 to 2005 among an office employee cohort working in a building with ongoing incomplete remediation. The incident asthma and HP cases among the 97 participants are sentinel events for a continued disease risk among the larger group of employees. The only factor that appeared to improve health indices over the 3-year interval was relocation within the building, probably due to microenvironments within the building and over time. We found that symptomatic individuals and those with abnormal lung function tests were more likely to leave employment. Future longitudinal intervention studies, incorporating building science assessment and attention to both individual exposures and health, are needed to answer the question what remediation, if any, is sufficient to decrease adverse respiratory health outcomes in those already affected. Since sensitized participants (like those who developed asthma and HP) may develop symptoms in response to lower exposures than those without previous sensitization, such employees should be relocated to a dry building or dry parts of the building away from remediation activities. Study of new employees without historical exposures may be required in assessing remediation effectiveness.

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