

Building-related respiratory symptoms can be predicted with semi-quantitative indices of exposure to dampness and mold

Abstract Using a semi-quantitative mold exposure index, the National Institute for Occupational Safety and Health (NIOSH) investigated 13 college buildings to examine whether building-related respiratory symptoms among employees are associated with environmental exposure to mold and dampness in buildings. We collected data on upper and lower respiratory symptoms and their building-relatedness, and time spent in specific rooms with a self-administered questionnaire. Trained NIOSH industrial hygienists classified rooms for water stains, visible mold, mold odor, and moisture using semi-quantitative scales and then estimated individual exposure indices weighted by the time spent in specific rooms. The semi-quantitative exposure indices significantly predicted building-related respiratory symptoms, including wheeze [odds ratio (OR) = 2.3; 95% confidence interval (CI) = 1.1–4.5], chest tightness (OR = 2.2; 95% CI = 1.1–4.6), shortness of breath (OR = 2.7; 95% CI = 1.2–6.1), nasal (OR = 2.5; 95% CI = 1.3–4.7) and sinus (OR = 2.2; 95% CI = 1.2–4.1) symptoms, with exposure–response relationships. We found that conditions suggestive of indoor mold exposure at work were associated with building-related respiratory symptoms. Our findings suggest that observational semi-quantitative indices of exposure to dampness and mold can support action to prevent building-related respiratory diseases.

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Key words: Dampness; Mold; Semi-quantitative exposure index; Respiratory symptoms; Building; Indoor air quality.

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Received for review 12 March 2004. Accepted for
publication 21 June 2004.

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Practical Implications

Current air sampling methods have major limitations in assessing exposure to mold and other biological agents that may prevent the demonstration of associations of bioaerosol exposure with health. Our study demonstrates that semi-quantitative dampness/mold exposure indices, based solely on visual and olfactory observation and weighted by time spent in specific rooms, can predict existence of excessive building-related respiratory symptoms and diseases. Relative extent of water stains, visible mold, mold odor, or moisture can be used to prioritize remediation to reduce potential risk of building-related respiratory diseases. From a public health perspective, these observational findings justify action to correct water leaks and repair water damage in order to prevent building-related respiratory diseases. This approach can also be a basis for developing practical building-diagnostic tools for water-incursion.

Introduction

Current airborne fungal sampling and analytical methods provide continuous scales of measurement for examining exposure–response relationships. They are, however, limited by potentially large sampling and analytical error, in addition to spatial and temporal variance of fungal levels (Hyvärinen et al., 2001). Large variability of bioaerosol measurements is likely to produce exposure misclassification in small sample

sizes, which may lead to the false conclusion that no association exists between exposure and health effects in epidemiologic studies (Park et al., 2000; Rappaport et al., 1995).

Various studies have linked respiratory symptoms and diseases with damp residential environments and mold growth (Hyndman, 1990; Jaakkola et al., 1993; Mohamed et al., 1995; Nafstad et al., 1998; Platt et al., 1989; Verhoeff et al., 1995). In these analyses, entire buildings or rooms within buildings were frequently

dichotomized into damp/not damp based on one or more of the following factors – visible mold, water stains, condensation, water damage, and mold odor – using self-reports, inspections, or humidity measurements (Bornehag et al., 2001). Such dichotomous distinctions can provide insight about possible associations with health effects, but may not provide adequate information to assess possible exposure–response relationships.

Faced with difficulties in bioaerosol measurement and inadequacies of dichotomous assessment of dampness, semi-quantitative methods of assessing exposure to dampness/mold based on visual and olfactory classification offer a potentially powerful and cost-efficient alternative approach for epidemiologic exposure–response studies of damp building environments (Haverinen et al., 2003).

The National Institute for Occupational Safety and Health conducted an investigation at a college where employees' concerns included building-related respiratory symptoms, asthma, and interstitial lung disease (Schleiff et al., 2002). In this study, we evaluated the presence of building-related respiratory symptoms and diagnoses. We also examined the utility of semi-quantitative dampness/mold exposure indices using observational measurements in predicting respiratory symptoms.

Methods

Study population and epidemiological survey

The college encompassed 40 buildings in which approximately 1231 full-time employees worked. Based on discussions with officials at the college, we selected all seven buildings that had a recurrent history of water incursion and related renovations (water-damaged buildings). We also selected six comparison buildings that were reported to have had little problem with water incursion (comparison buildings). We conducted a self-administered questionnaire survey of 554 full-time employees in these 13 buildings to obtain demographic characteristics, respiratory diagnoses and symptom data, and the time fraction spent in specific rooms. The respiratory question modules were from the European Community Respiratory Health Survey and the American Thoracic Society Questionnaires (EC Directorate General XIII, 1994; Ferris, 1978). The response rate of the full-time employees in the 13 buildings was 71% ($n = 393$). The response rate by primary building type (primary building is defined as the building in which a respondent spent most time during the school year) was 76% in water-damaged buildings and 59% in comparison buildings. We conducted a separate telephone survey of 161 non-participants about 4 months later, and the response rate was 39% ($n = 63$). Among the 393 participants in the main

survey, data for 323 employees for whom we had complete information about the amount of time worked in specific rooms during the fall semester were used for statistical modeling. We analyzed lower respiratory (wheeze, chest tightness, shortness of breath, and attacks of cough) and upper respiratory (nasal symptoms, sinus symptoms, and throat irritation) building-related symptoms reported to have occurred in the previous 12 months. Building-related symptoms were defined as those that improved away from work or for which medication use increased on workdays. Our investigation included a 'natural experiment' in which the majority of faculty members from one department had relocated within 8 months before the survey from one of the water-damaged buildings to three of the comparison buildings because of a high prevalence of respiratory illness.

Environmental evaluation

We inspected all 669 accessible rooms on all floors of 12 buildings and a randomly selected 25% ($n = 52$) of the rooms on each floor of the newest comparison building because of time and resource limitation. Using a standardized evaluation form, teams of industrial hygienists classified four environmental factors (water stains, visible mold, mold odor, and moisture) in seven areas of each room. The seven areas were: ceiling; walls; windows; floor; heating, ventilation, and air conditioning system; water pipes; and furniture. To check the validity of observations, two different teams independently cross-classified eight rooms in water-damaged buildings; concordance rates for individual environmental factors were 88% for water stain (from the comparison of dichotomous variables using median average-water-stain score), 63% for visible mold, 75% for mold odor, and 100% for moisture.

We graded water stains on a scale of 0–3 (0 = no water stains; 1 = water stains < 5% of the evaluated area; 2 = 5–30%; 3 = > 30%) for each area. We then averaged the scores over the seven areas within a room to give the average water-stain score (AWSS). Visible mold was documented when seen in any area. Mold odor was graded on a scale from no odor to slight to strong odor. We graded moisture as 'damp' if an area was moist to the touch or as 'wet' if visible water was observed. We also created two combined scores for each room using the environmental factors with different weights: (i) water-stain-weighted combination = 1.0 (if water stains) + 0.5 (if visible mold) + 0.5 (if mold odor) + 0.5 (if damp or wet); and (ii) visible-mold-weighted combination = 0.5 (if water stains) + 1.0 (if visible mold) + 0.5 (if mold odor) + 0.5 (if damp or wet). We gave more weight to either water stains or visible mold in these two combinations as those two environmental factors were most prevalent among all environmental factors.

Estimation of individual exposure index and data analysis

We estimated individual employees' exposure to each environmental factor or combinations of the environmental factors by the following equation:

$$\text{Individual exposure index (IEI)} = \sum_{i=1}^k (E_i \times \text{TF}_i),$$

where i = specific room; $E_i = 0$ (none) vs. 1 (any) for individual environmental factors, or continuous value for AWSS or each combination of four environmental factors, for room i ; and TF_i = estimated time fraction each individual spent in room i during the fall semester ($\text{TF}_{i \rightarrow k}$ sums to 1.0).

The IEI estimated from each individual factor was treated either as a dichotomous variable ('no' vs. 'any exposure'), or as a continuous variable for the AWSS. IEIs estimated from the combinations were also treated as continuous variables. In estimating IEIs for the occupants who spent some time in non-evaluated rooms in the newest building (in the comparison group), a zero value was assigned to the exposure for that time fraction.

We used generalized linear regression models to examine the association of AWSS with visible mold, mold odor, and moisture and to obtain least squares mean values (LSM) of AWSS (SAS Institute Inc., Cary, NC, USA). To compare building-related respiratory symptom prevalences between building groups, we used chi-square tests. We examined the association of IEIs with building-related respiratory symptoms using multivariate logistic regression models adjusting for age, gender, smoking, job status (faculty or staff), year of hire, presence of allergies, and use of latex gloves. We reported odds ratio (OR) and Wald's 95% confidence interval (CI). We used Somers' D statistics (SDS) of rank correlation to compare the predictive ability of the logistic models using the AWSS-based IEIs to those using the combination-based IEIs. We examined exposure-response relationships using quartiles of the AWSS-based IEIs and the visible-mold-weighted combination-based IEIs by symptom in the logistic models (SAS Institute Inc., Cary, NC, USA).

Results

Symptom prevalences

Among the 393 participants (mean age = 51, range = 35–65; 54% female; 87% white), approximately 30% reported at least one of the lower respiratory symptoms, about 60% reported nasal and/or sinus symptoms, and 40% reported throat irritation (Table 1). For each symptom, more than half of the symptomatic participants reported building-relatedness. Of the 393 participants, 43% reported asthma-like symptoms

Table 1 Demographic characteristics and prevalence of respiratory symptoms within the past 12 months for all participants ($N = 393$)

Characteristics/symptoms	No. of people	Prevalence (%)
Demographics		
Average age in years (s.d.)	51 (10)	–
Gender		
Female	214	54
Male	173	44
Not responded	6	2
Ethnicity		
White	344	87
African-American	22	6
Others	14	4
Not responded	13	3
Smoking status		
Non-smokers	262	67
Ex-smokers	113	29
Current smokers	16	4
Not responded	2	<1
Respiratory symptoms		
Lower respiratory symptoms		
Wheezing	129	33
Chest tightness	105	27
Shortness of breath	136	35
Attack of cough	113	29
Upper respiratory symptoms		
Nasal symptoms	238	61
Sinus symptoms	234	60
Throat irritation	163	41

(wheeze, or awakened by shortness of breath, or chest tightness around animals or dust, or continuous breathing troubles) (Burney et al., 1989), and 18% reported hypersensitivity pneumonitis (HP)-like symptoms (at least one lower respiratory symptom such as wheezing, chest tightness, shortness of breath with exertion, or usual cough, and any systemic symptom such as fevers, chills, night sweats, or flu-like achyness) (Arnow et al., 1978; Fox et al., 1999; Hodgson et al., 2001). Seventeen percent of the participants reported physician-diagnosed asthma, and half of those asthmatics reported building-relatedness.

The prevalence of any building-related respiratory symptom was significantly higher ($P < 0.02$) in the water-damaged building group than in the comparison building group ($\geq 20\%$ vs. $\leq 7\%$ for any lower respiratory symptom, and $\geq 34\%$ vs. $\leq 17\%$ for any upper respiratory symptom) (Figure 1).

Environmental evaluation

A higher prevalence of rooms with water stains, visible mold, mold odor, or moisture was observed in the water-damaged building group compared with the comparison building group (Table 2). The average AWSS of the rooms in the water-damaged buildings (0.80) was higher than that in the comparison buildings (0.38). The newest comparison building had an average

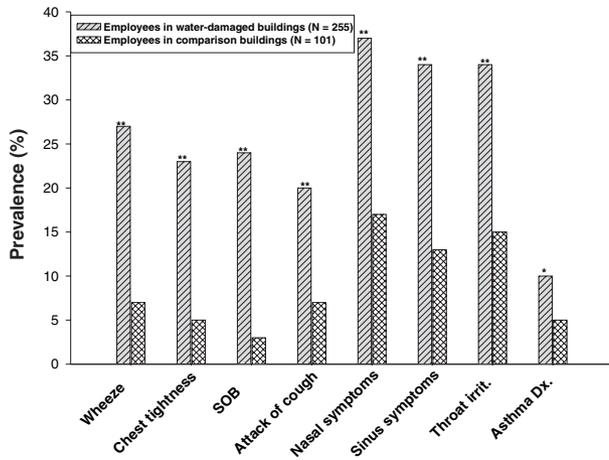


Fig. 1 Prevalence of building-related respiratory symptoms (wheeze, chest tightness, shortness of breath (SOB), attack of cough, nasal symptoms, sinus symptoms, throat irritation (throat irrit.), and physician-diagnosed asthma (asthma dx.) by building group. Only those who had responded to a question about the primary building they had been working in during school year were included in this analysis. A department in which the majority of faculty was relocated was excluded from the analysis (** $P < 0.02$; * $P = 0.14$ for chi-square test of two prevalences, adjusted for age, gender, smoking, job status, year of hire, allergies, and use of latex glove in models)

AWSS of 0.08, and only one of 52 rooms investigated had visible mold (data not shown).

In the multivariate analyses, water-damaged buildings had significantly higher ($P < 0.0001$) average AWSS (LSM = 0.81) than the comparison buildings (LSM = 0.44) after controlling for fixed effects of room type (classroom or office), floor, industrial hygiene team, temperature, and relative humidity. In logistic regression models controlling for room type, the water-damaged buildings showed significantly higher odds of visible mold (OR = 11.4; 95% CI = 4.0–31.9) and of mold odor (OR = 4.5; 95% CI = 1.1–19.3) compared with the comparison buildings.

Environmental factors were significantly correlated with one another. The average AWSSs were significantly higher ($P < 0.005$) in rooms with mold odor (0.99), visible mold (1.18), or damp/wet material (1.20) than in rooms without them (0.69, 0.62, 0.70, respectively). The odds of mold odor were four times

higher (95% CI = 1.9–8.4) in rooms with visible mold than in rooms without visible mold.

Association of IEIs with respiratory symptoms

The AWSS-based IEIs for the 323 employees ranged from 0 to 2.2 (mean = 0.63, median = 0.65, and s.d. = 0.43). The combination-based IEIs ranged from 0 to 1.8 (mean = 0.89, median = 1.0, and s.d. = 0.45) for the water-stain-weighted combination and from 0 to 1.6 (mean = 0.63, median = 0.5, and s.d. = 0.42) for the visible-mold-weighted combination. The IEIs based on AWSS or visible mold were more consistent predictors for building-related respiratory symptoms compared with IEIs based on mold odor or moisture (Table 3). In multivariate logistic models the AWSS-based IEI was a significant predictor for building-related wheeze (OR = 2.3) and throat irritation (OR = 2.4). Exposure to visible mold was associated with significantly increased building-related wheeze (OR = 2.0), chest tightness (OR = 2.6), shortness of breath (OR = 2.6), nasal symptoms (OR = 1.7), and sinus symptoms (OR = 2.0). Exposure to mold odor was associated with significantly increased throat irritation (OR = 2.3). We also found significant associations of the combination-based IEIs with building-related chest tightness, shortness of breath, nasal symptoms, and sinus symptoms (range of ORs = 2.2–2.7). We did not find significant associations of any of these exposure indices with physician-diagnosed asthma reported as building related. The odds of building-related wheeze, shortness of breath, nasal symptoms, and throat irritation generally increased as IEI increased in quartile analysis (Figure 2). Similar trends were also observed for other symptoms (not shown).

The AWSS-based IEI model appeared to be better in predicting wheeze and throat irritation than either of the combination-based IEI logistic models (SDS: 0.42 vs. 0.38, 0.39 for wheeze; 0.32 vs. 0.28, 0.29 for throat irritation). However, these models showed similar predictive abilities for all other building-related respiratory symptoms. The logistic model using the water-stain-weighted combination IEIs better predicted building-related nasal symptoms

Table 2 Distribution of observational measurements for rooms by building group

Building group ^a	No. of rooms	Water stains		Any visible mold N (%)	Any mold odor N (%)		Moisture condition N (%)	
		Continuous Mean (s.d.)	Any N (%)		Slight	Strong	Damp	Wet
Water-damaged buildings	558	0.80 (0.5)	549 (98)	109 (20)	23 (4)	7 (1)	4 (<1)	4 (<1)
Comparison buildings	163	0.38 (0.4)	122 (75)	4 (3)	2 (1)	0 (0)	0 (0)	0 (0)
Total	721	0.71 (0.5)	671 (93)	113 (16)	25 (3)	7 (<1)	4 (<1)	4 (<1)

^a Water-damaged buildings: buildings that had a recurrent history of water incursion and related renovations; comparison buildings: buildings that were reported to have had little or no problems with water incursion.

Table 3 Adjusted^a odds ratios (95% CIs) of respiratory symptoms for exposure indices from each environmental factor and from linear combinations of the environmental factors

Building-related respiratory symptoms	Water stains				Factor combinations		
	Continuous variable	Any stains	Any visible mold	Any mold odor	Any damp material or standing water	Water-stain-weighted ^b	Visible-mold-weighted ^c
Lower respiratory symptoms							
Wheeze	2.3 (1.1–4.5)	2.6 (0.7–9.2)	2.0 (1.1–3.7)	1.1 (0.5–2.3)	1.2 (0.3–4.5)	1.8 (0.9–3.5)	1.7 (0.9–3.4)
Chest tightness	1.9 (0.9–3.8)	1.9 (0.5–6.9)	2.6 (1.3–4.9)	1.01 (0.5–2.2)	1.0 (0.2–4.2)	1.8 (0.9–3.8)	2.2 (1.1–4.6)
Shortness of breath	1.7 (0.8–3.6)	6.3 (0.8–51.1)	2.6 (1.3–5.1)	1.4 (0.7–3.2)	3.3 (0.9–11.9)	2.7 (1.2–6.1)	2.5 (1.2–5.4)
Cough	1.3 (0.6–2.6)	3.2 (0.7–14.4)	1.5 (0.8–2.8)	1.7 (0.8–3.6)	1.0 (0.2–4.5)	1.5 (0.7–3.2)	1.7 (0.8–3.6)
Upper respiratory symptoms							
Nasal	1.5 (0.8–2.8)	4.4 (1.2–15.3)	1.7 (1.0–3.0)	1.1 (0.6–2.1)	1.7 (0.5–6.0)	2.4 (1.3–4.6)	2.5 (1.3–4.7)
Sinus	1.6 (0.9–2.9)	3.8 (1.1–13.4)	2.0 (1.2–3.4)	1.3 (0.7–2.5)	0.8 (0.2–2.9)	1.8 (1.0–3.4)	2.2 (1.2–4.1)
Throat irritation	2.4 (1.3–4.4)	2.0 (0.7–5.6)	1.3 (0.7–2.1)	2.3 (1.2–4.3)	1.5 (0.4–5.1)	1.6 (0.9–3.0)	1.5 (0.8–2.8)

^a Adjusted for age, gender, smoking, job status, year of hire, allergies, and use of latex glove in logistic regression models. Boldfaced odds ratios are statistically significant ($P < 0.05$).
^b Water-stain-weighted index: 1 (if water stains) + 0.5 (if visible mold) + 0.5 (if mold odor) + 0.5 (if damp or wet).
^c Visible-mold-weighted index: 0.5 (if water stains) + 1 (if visible mold) + 0.5 (if mold odor) + 0.5 (if damp or wet).

than that using only the AWSS-based IEIs (SDS: 0.41 vs. 0.37). Both the combination-based and the AWSS-based IEI models did best predicting building-related shortness of breath (SDS: 0.48–0.50) compared with other building-related respiratory symptoms (SDS: 0.28–0.43).

Relocation and non-respondent surveys

To supplement the associations between dampness/mold exposure indices and building-related respiratory symptoms, we examined the effect of employee relocation from a water-damaged building to comparison buildings. Of the 26 relocated employees, 14 employees (54%) reported building-related respiratory symptoms while they worked at the water-damaged building. Of

these 14, 36% reported that their symptoms had either lessened or completely resolved after the relocation.

In the non-respondent survey, the major reasons given for non-response in the main study were unrelated to health. The only demographic difference between respondents and non-respondents was a higher proportion of males among non-respondents (56% vs. 44%). The prevalence of physician-diagnosed asthma was almost identical between respondents (17%) and non-respondents (16%), although respondents were more likely to have any chest symptom than non-respondents (46% vs. 30%). Non-respondents in the water-damaged building group had increased symptom prevalence compared with non-respondents in the comparison building group, as was found for respondents.

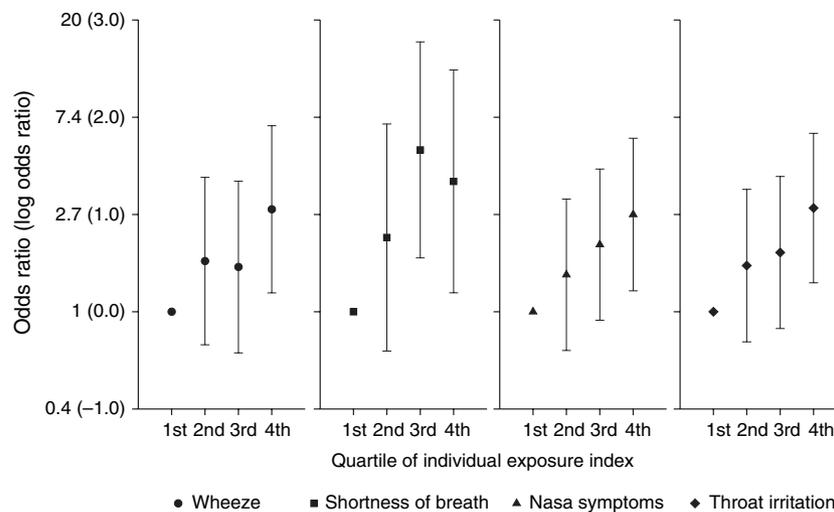


Fig. 2 Exposure–response relationships across quartiles of individual exposure indices (IEIs) and work-related respiratory symptoms. Quartiles based on AWSS-based IEIs for wheeze and nasal symptoms; quartiles based on the visible mold-weighted combination IEI for shortness of breath and throat irritation. Similar trends were also observed for other symptoms (not shown)

Discussion

Building-related respiratory symptoms and diagnoses

Three pieces of evidence combine to suggest a relationship between building conditions and symptom prevalence in our study. First, the distribution of symptoms and physician diagnoses across the two building populations was uneven. In this, the prevalences of building-related respiratory symptoms and damp conditions were both considerably higher in the water-damaged building group than in the comparison building group, suggesting that occupants' symptoms may have resulted from building conditions. Secondly, improvement or resolution of symptoms among a portion of employees relocated from a water-damaged building to other buildings suggests that their symptoms may have been caused by exposure in the water-damaged building. Thirdly, and most important, our statistical models demonstrated not only associations but also exposure–response relationships between semi-quantitative dampness/mold exposure indices and building-related respiratory symptoms.

Consistent with building-related respiratory disease, the college employees in the water-damaged building group had an excess of symptoms and physician-diagnosed asthma in comparison with two external groups. First, compared with occupants of US office buildings not known to have indoor air quality complaints, the college employees had higher prevalences of lower respiratory symptoms (>27% vs. <6%) and upper respiratory symptoms (>41% vs. <14%) (Apte et al., 2000). Secondly, the college employees also reported more physician-diagnosed asthma (18%) than adult residents in the same state (11%) (National Center for Chronic Disease Prevention and Health Promotion, 2001).

Building-related asthma is characterized by chest tightness, wheezing, cough, and shortness of breath with one of several patterns of exacerbation related to building occupancy. Building-related HP is characterized by chest symptoms often accompanied by fevers, chills, or flu-like achyness related to building occupancy. Likewise, building-related allergic rhinitis is suspected when building occupants have nasal symptoms and sneezing in relation to building occupancy (Kreiss, 1989). In our study, many persons with asthma- or HP-compatible symptoms did not report a physician diagnosis of either. Other investigators have reported that over 70% of those with asthma symptoms and airflow obstruction in the general population are not diagnosed with asthma (van Schayck et al., 2000). Similarly, in outbreaks of HP and other similar granulomatous lung diseases, symptomatic cases may not be diagnosed as such by physicians (Rose et al., 1998; Sanderson et al., 1992). Therefore, the symptoms reported in our study may

reflect the presence of building-related diseases even among those not specifically diagnosed.

Semi-quantitative dampness/mold exposure indices

Our study shows that semi-quantitative dampness/mold exposure indices created from visual and olfactory observations predicted building-related respiratory symptoms in 13 buildings on this college campus. In our study, trained industrial hygienists assessed room environments rather than relying on occupant-reported exposures, which are subject to information bias. Many studies have reported the association of damp environments with respiratory health using dichotomous assessment of exposure (Andriessen et al., 1998; Brunekreef, 1992; Dales et al., 1991b; Jaakkola et al., 2002). To minimize bias due to an arbitrary choice of dichotomous exposure criteria (Bornehag et al., 2001), we developed a continuous exposure scale using a time-weighted semi-quantitative assessment tool for dampness/mold. By treating a semi-quantitative scale as a continuous variable in the statistical models, we could examine exposure–response relationships.

Haverinen et al. (2001) showed that a three-level classification of water-damage for entire residential buildings, using both the amount of moisture damage and its severity, better predicted health symptoms than a two-level (no/minor vs. moderate/severe water damage) classification. They demonstrated exposure–response relationships using the three-level classification. Our evaluation for water stains was a four-level classification based on the percentage of area stained in seven different areas in each room and all our IEIs were weighted for time spent in particular rooms, yielding continuous variables for statistical modeling. Our quartile analyses of continuous IEIs showed that an increasing exposure to dampness/mold was generally associated with elevated odds of building-related respiratory symptoms.

Our observation of exposure–response relationships for several building-related respiratory symptoms suggests that our exposure indices may be valid surrogates for the related exposure(s). Although the specific microbial cause(s) remains unknown, a robust body of knowledge exists to support the association of moisture incursion in residences with risk of asthma and respiratory symptoms (Andriessen et al., 1998; Brunekreef, 1992; Dales et al., 1991a; Haverinen et al., 2001). Our study adds to the existing evidence indicating that the same risks occur in water-damaged non-residential buildings (Jarvis and Morey, 2001; Li et al., 1997; Savilahti et al., 2000; Wan and Li, 1999). Dales et al. (1997) showed that self-reported mold odor was associated with total culturable fungi in settled dust, and visible mold growth in homes was associated with increased levels of *Aspergillus* and *Penicillium* in settled

dust. Garrett et al. (1998) also reported similar associations of mold odor, visible mold growth, and water damage with airborne spore level in Australian residential environments.

Water stains and visible mold were the most prevalent of the investigated environmental factors, and the IEs based on water stains and visible mold were better predictors of building-related respiratory symptoms than were other IEs. Therefore, evaluating rooms for water stains and visible mold with a time-weighted semi-quantitative scale promises to be an efficient tool for exposure assessment in damp buildings. Although building-related nasal symptoms were better predicted by the water-stain-weighted combination IEI, prediction of other symptoms was not benefited by combining all environmental factors compared with using single-factor IEs. Our combination-based IEs lack a theoretical basis for the weights assigned to each factor. Further work is necessary to understand the relative contribution of each factor to predicting symptoms and the optimal combination index for dampness/mold exposure assessment.

Limitations and strengths

Our approach, as applied in this study, has at least three limitations. First, exposure underestimation would result if past remediation removed visual evidence of prior water incursion without removing hidden reservoirs of microbial agents. Secondly, inconsistency among industrial hygienists might limit the reliability of the exposure index. Thirdly, exposure of occupants in the newer comparison building may have been misclassified by assigning zero exposure to rooms that had not been evaluated for dampness/mold. All of these limitations may introduce possible misclassification of occupants' exposure. However, because our industrial hygienists were blind to workers' health, the exposure misclassification was not likely to be affected by health status (non-differential misclassification) (Rothman and Greenland, 1998) and thus most likely equivalent in both directions of health outcomes. Given that our dichotomous exposure variables strongly predicted the risk of respiratory symptoms, this misclassification of exposure is unlikely to have exaggerated the associations we found because non-differential misclassification of a dichotomous exposure biases the association toward no association (Rothman and Greenland, 1998).

Evidence that exposures in damp or moldy rooms led to the excesses in respiratory symptoms observed in our study is supported by the associations detected and by the reported amelioration of symptoms following relocation of affected employees. As is typically found with studies involving subjective responses (Strachan, 1988) it is possible that our

study findings were impacted by over- or under-reporting of symptoms by individuals who were cognizant of conditions in their working environment. To partially address this issue, we examined relationships between non-building-related respiratory symptoms and exposure indices, and found no positive associations (data not shown). In analyses limited to occupants in water-damaged buildings, we observed the same trends of increased risks of chest symptoms in employees exposed to visible mold compared with those not exposed (ORs = 1.2–1.5; $P = 0.3$ – 0.6) and nasal (OR = 1.5, $P = 0.2$) and sinus (OR = 1.7, $P = 0.1$). In this case, however, we had little statistical power due to the smaller sample size. These results suggest that reporting bias by employees who perceived damp rooms and were more likely to report health symptoms is minimal. However, accurate assessment of the degree of any reporting bias is not possible with our data. Participation bias, because of greater participation of symptomatic employees compared with non-symptomatic employees, could have influenced our findings as we observed a higher response rate from the water-damaged building group than from the comparison building group. However, both main study participants and resurveyed non-participants had similar symptom distribution patterns across the building populations and almost identical prevalence of physician-diagnosed asthma. Therefore, participation bias is unlikely to account for the results in our findings or our conclusions.

The strength of our semi-quantitative observational approach is its efficiency in comparison to traditional bioaerosol sampling methods. Short-term air sampling for culturable fungi or spores has limited reliability because of large temporal and spatial variability of airborne fungi (Macher, 1999). Therefore, to avoid exposure misclassification in large epidemiologic studies of building-related symptoms, it is necessary to collect many samples to obtain representative exposure measurements, an approach that is extremely expensive and time consuming. Thus, in most epidemiologic studies characterized by limited resources, exposure misclassification with bioaerosol sampling is unavoidable, which may explain the usual inability to detect associations between building-related symptoms and traditional bioaerosol measures. Given this lack of feasible tools for reliably measuring exposure to fungi in extensive indoor environments, our observational semi-quantitative method for assessing occupant exposure to conditions that promote or indicate bioaerosol amplification is especially promising.

Conclusions

We found excessive building-related respiratory symptoms in relation to damp environments. Our

semi-quantitative dampness/mold exposure indices, weighted by time spent in specific rooms and based solely on visual and olfactory observation, were associated with building-related symptoms that may reflect asthma, HP, and nasal/sinus disease. Our findings demonstrate the usefulness of the observational semi-quantitative approach for exposure assessment in large epidemiologic studies. Our semi-quantitative method suggests that not only is the presence of water stains, visible mold, mold odor, or moisture important for predicting building-related respiratory diseases, but also that the relative extent of these factors can be used to prioritize remediation to reduce potential risk of building-related respiratory diseases. From a public health perspective, these observational findings justify action to correct water leaks and repair water damage in order to prevent

building-related respiratory diseases. Although not addressed by our study, hidden reservoirs of microbial contamination should not be ignored in remediation of water-damaged buildings.

Acknowledgements

We thank C. Rao, C. Piacitelli, D. Yereb, R. Boylstein, and K. El-Sherbini for assistance with the development of an environmental evaluation sheet or for the collection of environmental data. We thank Dr. Robert Castellan, Dr. Terri Pearce, and Dr. Eva Hnizdo for review of the manuscript and helpful comments. We also thank William Turner for providing good discussion regarding development of semi-quantitative observational methods.

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