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Exploration of the effects of classroom humidity levels on teachers' respiratory symptoms

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Abstract

Purpose—Previous studies indicate that teachers have higher asthma prevalence than other non-industrial worker groups. Schools frequently have trouble maintaining indoor relative humidity (RH) within the optimum range (30-50%) for reducing allergens and irritants. However, the potential relationship between classroom humidity and teachers' health has not been explored. Thus, we examined the relationship between classroom humidity levels and respiratory symptoms among North Carolina teachers.

Methods—Teachers (n=122) recorded daily symptoms, while data-logging hygrometers recorded classroom RH levels in 10 North Carolina schools. We examined effects of indoor humidity on occurrence of symptoms using modified Poisson regression models for correlated binary data.

Results—The risk of asthma-like symptoms among teachers with classroom RH >50% for five days was 1.27 (0.81, 2.00) times the risk among the referent [teachers with classroom RH 30-50%]. The risk of cold/ allergy symptoms among teachers with classroom RH >50% for five days was 1.06 (0.82, 1.37) times the risk among the referent. Low RH (<30%) for five days, was associated with increased risk of asthma-like [Risk Ratio (RR): 1.26 (0.73, 2.17)] and cold/allergy symptoms [RR: 1.11 (0.90, 1.37)].

Conclusions—Our findings suggest that prolonged exposure to high or low classroom RH was associated with modest (but not statistically significant) increases in the risk of respiratory symptoms among teachers.

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COMPLIANCE WITH ETHICAL STANDARDS
Competing Interest Statement
The authors declare they have no competing interests.

Ethical Approval
The University of North Carolina's Institutional Review Board approved all research procedures and materials (IRB# 10-1150). All procedures performed this study involving human participants were in accordance with the ethical standards of the Institutional Review Board and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed consent
Informed consent was obtained from all individual participants included in this study.

Keywords

Teachers; Asthma; Allergies; Longitudinal Study; Workplace; Classroom Humidity

INTRODUCTION

Although teaching is considered an occupation with few, long-term health hazards, recent studies found that teachers have a higher prevalence of asthma compared to other non-industrial, occupational groups and a similar prevalence of asthma to blue collar workers (8.8% vs. 8.6%) (Eng et al. 2010; Whelan et al. 2003). Two occupational surveillance studies found that the highest proportion of work-related asthma cases were among educational employees (Fletcher et al. 2006; Mazurek et al. 2008). Despite this intriguing evidence, teachers are not typically the subjects of work-related asthma studies.

Common asthma triggers include viral infections, aeroallergens (e.g. mold, dust mites), and chemical or particulate irritants (Global Initiative for Asthma (GINA) 2014). Changes in temperature and humidity may also directly cause acute airway inflammation, hyperresponsiveness, or irritation; or indirectly cause symptoms by increasing chemical emissions or aeroallergens (Arlian et al. 2002; Buckley and Richardson 2012; Chao et al. 2002; Global Initiative for Asthma (GINA) 2014; Jaakkola 2006; Matthews et al. 1986). Asthma triggers prevalent in damp environments have been reported in middle schools in North Carolina (NC), a state with a fairly humid climate throughout the year (Mirabelli et al. 2006). The U.S. Environmental Protection Agency's (US EPA) Indoor Air Quality (IAQ) Tools for Schools Action Kit recommends that indoor RH levels should ideally be between 30-50%, or at least below 60% (U.S. EPA 2009). Controlling classroom humidity may be an effective strategy to prevent asthma and allergy symptoms among teachers.

School occupants may suffer from extremely high and extremely low humidity depending on the time of year, and both have been linked to adverse health effects (Angelon-Gaetz et al. 2015). Indoor dampness has been associated with asthma exacerbation, coughing, wheezing, bronchitis, and upper respiratory infections (Fisk et al. 2010; World Health Organization 2009). Low RH may cause drying and irritation of skin and mucous membranes, increasing susceptibility to viral infection (Sato et al. 2003; Shaman and Kohn 2009; Wolkoff and Kjaergaard 2007). Both excessive moisture and excessive dryness may also increase transmission and survival of upper respiratory viruses (Casanova et al. 2010; Karim et al. 1985; Lowen et al. 2007; Sattar et al. 1987; Shaman and Kohn 2009). Thus, we measured the effect of classroom humidity levels on teachers’ respiratory symptoms.

METHODS

We conducted a longitudinal study of school IAQ factors and health effects among kindergarten through twelfth grade teachers in North Carolina, USA. Data were collected in two phases-- from October 16 to December 10, 2010 in four schools, and from February 6 to June 11, 2011 in six schools.

We invited 20 NC school district administrators to enroll their districts in our study. Superintendents from two school districts responded and met the eligibility requirement (participation from at least three school principals). To promote community ownership of the research, our district maintenance office liaisons chose which principals were contacted for inclusion in the study. We used a non-probability, heterogeneity sampling of the schools and encouraged liaisons to recruit schools in different grade and resource levels. Principals were required to sign a letter of consent for employee participation in research activities before teacher recruitment.

Through email and faculty meetings, we invited all full-time teachers (work ≥30 hours/ week) to participate. To enroll in the study, teachers were required to attend a presentation to learn about study procedures, risks, and benefits. Consented teachers completed an enrollment survey, administered online through Qualtrics Research Suite (Qualtrics Labs, Inc. Provo, 2011) and were assigned unique participant identifiers. Where feasible, recruitment presentations were scheduled during regular staff meetings. Enrollment dates were staggered by school, based on available meeting dates.

The enrollment survey consisted of baseline questions on work history and demographics, and questions from the 2008 Behavioral Risk Factor and Surveillance System "Asthma Call-back Questionnaire for Adults" which assessed home exposures and chronic respiratory diagnoses (Centers for Disease Control and Prevention 2009).

Participants recorded daily symptoms from the previous week at the start of each work week for 4 to 12 weeks in "Weekly Health Diaries" (WHD) (see Surveys, Supplemental Materials). Phase 1 WHD were self-administered, paper surveys; whereas, Phase 2 WHD were administered online through Qualtrics (Qualtrics Labs, Inc. Provo, 2011).

To capture asthma-like symptoms in undiagnosed teachers and weekly symptom variations in asthmatic teachers, we asked all participants about respiratory symptoms indicative of asthma. We defined the primary outcome, "asthma-like symptoms," as "1" for each person-day with reported wheezing, chest pain, chest tightness, shortness of breath, and/or dry cough.

Because allergies and viral respiratory infections may precede development of asthma, we were also interested in cold/ allergy symptoms (Global Initiative for Asthma (GINA) 2014). Since cold symptoms are indistinguishable from allergy symptoms, we grouped cold and allergy symptoms together. Thus, we defined the secondary outcome, "any cold/allergy symptoms," as "1" for each person-day with reported productive cough; itchy eyes; itchy, scratchy throat; stuffy nose; runny nose; sneezing; and/or sore throat. However, since influenza may have a different etiology than colds or allergies, we defined "any cold/allergy symptoms" as "0" if participants reported fever with a cough and/or sore throat, indicating influenza-like illness according to the Centers for Disease Control case definition (http://www.cdc.gov/flu).

We performed a baseline inspection of participants' classrooms and common areas according to IAQ Tools for Schools Walkthrough Inspection procedures, noting any potential asthma triggers or ventilation issues, and recording classroom IAQ parameters (e.g.

carbon dioxide) (U.S. EPA 2009). We retrospectively surveyed district maintenance liaisons about building operations policies and heating, ventilation, and air conditioning (HVAC) equipment used during our data collection period.

The NC State Climate Office provided daily outdoor RH and temperature averages for the closest station to each study site. The NC Department of Public Instruction provided district level teacher demographic data. Each school district provided school-level information on teacher tenure and educational attainment.

With the permission of participants, we monitored their classrooms using Extech data logging hygrometers programmed to record indoor RH and temperature every 15 minutes. We placed hygrometers near the participants' breathing zones where the participant usually stood or sat (e.g. teacher's desk). Before and during data collection, we tested hygrometers for accuracy and precision against a sling psychrometer, the "gold standard" instrument for measuring relative humidity (Gaetz 2014).

Though some participants worked in multiple classrooms, we limited the analysis to measurements from their primary classrooms, since we did not record participants' movements between classrooms. A participant's primary classroom was defined as the room in which she spent the most time. RH observations were averaged over each day, by classroom. We categorized daily average RH levels using three indicator variables: low (<30%) vs. recommended level 1 (30-50%), high (>50%) vs. recommended level 1 (30-50%), and high (>60%) vs. recommended level 2 (30-60%). To get a measure of humidity independent from temperature, we converted RH to absolute humidity (AH) (see Equations S2-S5, Supplemental Materials). Data were managed, imputed and analyzed in SAS V9.3 (SAS Institute, Cary. 2011).

We performed multiple imputation of missing outcome data (7.34 % for asthma-like symptoms; 7.67% for cold/ allergy symptoms) to improve the accuracy of our model estimates (Beunckens et al. 2008). Multiple imputation is a technique that replaces missing data with expected values from a distribution of model estimates created by modeling the relationship between the incomplete variable and other known/ more complete variables. (See Donders et al. 2006 for a more thorough explanation of imputation modeling methodology and Gaetz 2014 for a more detailed explanation of how the imputation models were created for this manuscript.) Imputation models (m=20) included potential confounders associated with both the exposure and outcome in the literature, all variables correlated with the outcome, and all variables strongly associated with missing outcome. Continuous indoor RH and temperature (missing=3.80%) were also imputed using variables associated with exposure and with missing exposure as described in detail elsewhere (Angelon-Gaetz et al. 2015). The imputed average RH was then coded as indicator variables described above.

We asked participants to record the number of hours spent at school to determine whether or not they were "exposed" to classroom RH levels. We defined presence in the classroom as "1" if the participant reported any hours (>0) in the school building on a given day. We instructed participants, "For days in which you did not enter your school building, write "0."" Therefore, if a participant was away on a fieldtrip, we did not count her as present on that day. Weekends were coded as "presence=0," since we did not instruct participants to record weekend hours at school.

We estimated the association between dichotomous classroom RH levels and asthma-like and cold/allergy symptoms on day=t. We fit bivariate and multivariate Generalized Estimating Equation (GEE) models (Supplemental Materials, *Equation 1S*) using the modified Poisson regression approach for correlated binary data (Zou and Donner 2013). Since outcome occurrences (event=1) closer in time were more correlated than outcome occurrences further apart in time, an autoregressive (AR) error correlation matrix was used to model time-dependence.

We specified three *a priori* criteria for order of covariate removal through backward selection-- variable not indicated as a confounder in relational diagrams constructed based on current literature, variable not in the original analysis plan, and variable had a high p-value (>0.05) in the full model (Gaetz 2014). Variables were ranked in order of removal according to how many criteria they met. We then dropped covariates whose removal improved precision and changed the main estimate by <5%. The following covariates were assessed for inclusion as potential confounders of the association between humidity and respiratory symptoms: gender; outdoor temperature; presence in school building; baseline allergy status; frequency of heating, ventilation, and air conditioning system maintenance; programmed thermostat setbacks; economizer use (to control air flow); building age; and window opening behaviors. Of these covariates tested, only outdoor temperature met our *a priori* criteria for inclusion.

We modeled zero, one and two-day lags between the exposure and outcome. For example, models with the two-day lag estimated the association between the respiratory outcome on day= t and the RH observation from two days before the outcome (day=t-2). Since teachers absent from school on a given day were not exposed to the classroom environment, we focused on the association between exposure and outcome among those present on the day of exposure measurement (unlagged model) and those present during exposure measurement and symptoms 1 day (or 2 days) later (lagged model).

To assess the effects of repeatedly high or low humidity in a given week, we created cumulative exposure variables. Within each seven-day period, we replaced any missing values with the average humidity during the observed days. Adjusted cumulative exposure variables were calculated from the sum of days on which teacher presence= "1" and classroom RH was high or low in a seven-day window. We assigned the value "0" to days with recommended RH and "missing" to days not present. Since teachers were considered not present on weekends, the maximum number of days exposed to classroom RH was five. For adjusted cumulative AH, we calculated the average AH within the seven-day window, using only data from those days on which presence= "1." On days when presence= "0," AH was considered missing.

RESULTS

Of 569 eligible teachers, 122 (21%) enrolled in the pilot study, with 85.2% participant retention until the end of follow-up. Phase 2 participants had a higher survey completion rate (77.9%) than Phase 1 participants (69.4%), despite the longer follow-up time in Phase 2. Compared to the target population, participants were more likely to be female, white, and have a post-bachelor's education (Gaetz 2014).

The baseline prevalence of self-reported, physician-diagnosed asthma was 14.8% (Table 1). However, 16% of all participants reported at least one asthma-like symptom during follow-up, and 11% of all participants reported wheezing at least once (Table 2). The baseline prevalence of self-reported atopy was 52.5% (Table 1), and over half of all participants reported cold/ allergy symptoms at least once during follow-up (Table 2). Cold/ allergy symptoms were reported on almost 20% of person-days compared to asthma-like symptoms, which were reported on 3% of person-days (Table 2).

The association between classroom RH >50% and risk of asthma-like symptoms was similar in magnitude and direction for lagged versus non-lagged exposure models (Table 3). The risk of asthma-like symptoms among those present with classroom RH >60% on a given day was 0.88 (95% CI: 0.52, 1.50) times the risk among the referent (those present with RH 30-60%). However, the risk of asthma-like symptoms among those present with classroom RH >60% two days prior was 1.13 (95% CI: 0.69, 1.84) times the risk among the referent. The risk of asthma-like symptoms among those present with classroom RH <30% on a given day was 1.05 (95% CI: 0.78, 1.42) times the risk among the referent (Table 3). However, the association between classroom RH <30% and risk of asthma-like symptoms was less than null (RR=1.0) after a two-day exposure lag [RR=0.84 (0.62, 1.15)].

The association between classroom RH >50% and risk of cold/ allergy symptoms was close to null for lagged and non-lagged exposure models (Table 4). However, the association between RH >60% and risk of cold/ allergy symptoms was greater than null for the model with no lag [RR=1.10 (0.91, 1.32] and one-day lagged exposure [RR=1.06 (0.87, 1.30)]. For the two-day lagged exposure model, the association between RH >60% and risk of cold/ allergy symptoms was null [RR=0.99 (0.80, 1.23)]. The association between classroom RH <30% and risk of cold/ allergy symptoms was approximately null for the unlagged and one-day lag models, but slightly higher than null for the two-day lagged model (Table 4).

The associations between 1 g/m^3 increase in absolute humidity and risk of asthma-like symptoms and cold/ allergy symptoms were close to null across almost all lag periods (Tables 3 and 4). However, the association between absolute humidity and asthma-like symptoms was slightly below null for the unlagged model [RR=0.95 (0.89, 1.03)] (Table 3).

The risk of asthma-like symptoms among teachers present with repeated (for five days) exposure to classroom RH >50% was 1.27 (95% CI: 0.81, 2.00) times the risk among the referent (Table 5). However, the risk of asthma-like symptoms among teachers with repeated classroom RH>60% was 0.92 (0.28, 3.01) times the risk among the referent. Due to the small number of observations with RH>60%, the CI were much wider than the CI for the RH>50% estimates. Risk ratios describing the association between repeated high RH, both

>50% and >60%, and cold/allergy symptoms were close to null. The risk of asthma-like symptoms among teachers present with repeated classroom RH <30% was 1.26 (95% CI: 0.73, 2.17) times the risk among the referent (Table 5). The association between repeated exposure to RH<30% and risk of cold/allergy symptoms was 1.11 (95% CI: 0.90, 1.37). Increased cumulative average absolute humidity had an inverse association with risk of asthma-like symptoms and cold/ allergy symptoms on the seventh day (Table 5).

Risk ratios for the association between low RH and risk of respiratory symptoms from cumulative exposure models unadjusted for teachers' presence at school were closer to the null but more precise than risk ratios from models adjusted for teachers' presence (see Table S1, Supplemental Material). For both adjusted and unadjusted exposure models, increases in cumulative average absolute humidity over a 7-day period had an inverse association with risk of asthma-like and cold/ allergy symptoms on the seventh day (Tables 5 and S1).

DISCUSSION

This study contributes novel evidence on the longitudinal relationship between classroom humidity and risk of teachers' respiratory symptoms to the existing literature on dampness and respiratory health effects among school building occupants. We found a high prevalence of medically diagnosed asthma and self-reported allergies at baseline among participants. Cold/allergy symptoms did not appear to be associated with high (>50%) or low (<30%) classroom RH, even after the lag period between RH exposure and respiratory outcome was varied. There was a slightly elevated, though non-statistically significant association between asthma-like symptoms and high (>50%) RH for all lag periods. With a two day lag of low (<30%) RH, the association was less than null, which could possibly indicate a reduction in moisture related allergens. Exposure to five days of high (>50%) or low (<30%) classroom RH was associated with increased risk of both asthma and cold/ allergy symptoms, which is suggestive of a cumulative effect of indoor RH on the human body. These effects may be immunological, inflammatory responses to the climatic conditions themselves or to aeroallergens and other indoor pollutants that may be increased at extreme values of RH.

The baseline prevalence of ever diagnosed asthma (14.8%) was higher among participants compared to all NC adults surveyed during the same time period [13.2 (95% CI: 12.2-14.3)] (Behavioral Risk Factor Surveillance System (BRFSS) Calendar Year 2010 Results 2011). No participants reported new asthma diagnoses during the study; however, we were not able to clinically evaluate them. Most who reported asthma-like symptoms had never been diagnosed with asthma. Since clinical evaluation is the current "gold standard", the "true" baseline prevalence of asthma among participants may have been even higher than reported.

We found evidence that presence at school independently increased participants' risk of respiratory symptoms. Classroom inspections suggested that allergens (e.g. mold) and irritants (e.g. dust) were present in most classrooms. We found only 10 studies on mold and water damage which focused on health consequences for school employees (Bakke et al. 2008; Dangman et al. 2005; Ebbehoj et al. 2005; Kielb et al. 2014; Park et al. 2004; Patovirta et al. 2004; Rudblad et al. 2001; Sahakian et al. 2008; Thomas et al. 2012; Thorn et al. 1996). Seven of the eight studies focusing specifically on teachers showed strong associations between dampness, mold and respiratory symptoms (Dangman et al. 2005; Kielb et al. 2014; Park et al. 2004; Patovirta et al. 2004; Rudblad et al. 2001; Sahakian et al. 2008; Thomas et al. 2012). However, these studies may not be directly comparable with our study due to the wide variation in exposure and outcome assessment methods.

A major strength of this study was the repeated measurement of classroom humidity and teachers' daily symptoms, with good subject retention and survey completion, using appropriate statistical methods to account for clustering by participant. The short survey recall period was designed to maximize outcome measurement accuracy, and data logging hygrometers provided precise, repeated exposure measurements. Since both outcome and exposure data were likely missing at random and missing data patterns were related to other complete variables, we imputed missing values to improve our model estimate accuracy. To our knowledge, this is the first study examining quantitative humidity measurements with longitudinal measures of teachers' health outcomes. Since we measured RH using low cost instruments, this study could be easily replicated on a larger scale.

Most participants reported IAQ issues at home; thus, symptoms may be responses to some combination of workplace and home exposures. We found limited variability in home environment questions, which were only measured at baseline, and could not assess potential interactions with school environment. Likewise, few participants were current smokers (Table 1), so we could not control for smoking. Smoking status should not be related to classroom RH levels, so it should not bias the relationship between RH and respiratory symptoms.

Unmeasured, acute exposures from other school rooms (e.g. faculty lounge) could have triggered respiratory symptoms. We did not collect prospective information about teachers' locations and so could not account for exposures in other classrooms. Since the average length of time that participants worked in their primary classrooms was 39.4 ± 9.34 hours, exposure misclassification due to movement between rooms should be negligible for most participants.

We recruited participants using a non-random sampling method. This study was not designed to determine the baseline prevalence of asthma and allergies among all North Carolina teachers. During Phase 2 recruitment, we emphasized the need for both asthmatic and non-asthmatic participants to improve the representativeness of our sample. Thus, Phase 1 participants were more likely than Phase 2 participants to be asthmatic, with Phase 2 asthma prevalence similar to that of the general population. Since perceived humidity and baseline asthma may have been related to enrollment and phase, adjustment for phase could have introduced bias, so we decided to exclude this variable from the models.

Our study was not designed to examine biological mechanisms by which extreme RH can trigger asthma-like symptoms. However, another recent study found an association between a 10% increase in RH and DNA methylation changes for genes related to inflammation which could influence asthma development (Bind et al. 2014). Also, we expect that maintaining classroom RH levels between 30-50% would reduce allergens and irritants, which would reduce the risk of asthma development. Thus, possible mechanisms for the relationship between extreme classroom RH and asthma-like symptoms that should be explored in future research include both direct effects of RH on inflammatory pathways and indirect effects of extremely high or low RH by providing a hospitable environment for allergens and pathogens.

In summary, we found a modest though not statistically significant increase in asthma-like symptoms at both RH >50% and <30%, with fairly precise estimates. We found no effects of RH on cold/allergy symptoms. Since asthma-like symptoms may decrease teachers' productivity, quality of life, and disrupt classroom learning, controlling RH may be a practical way to improve teachers' job-related satisfaction and classroom environments at the same time.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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TABLE 1

BASELINE CHARACTERISTICS OF PARTICIPANTS[a]

Characteristic	Subgroup	Phase 1 N (%)	Phase 2 N (%)	Total N (%)
Total		36 (100)	86 (100)	122 (100)
Gender	Male	3 (8.3)	16 (18.6)	19 (15.6)
	Female	33 (91.7)	70 (81.4)	103 (84.4)
Race[b]	Black	2 (5.6)	3 (3.5)	5 (4.1)
	White	33 (91.7)	83 (96.5)	116 (95.1)
	Other	1 (2.8)	4 (4.7)	5 (4.1)
Ethnicity[c]	Hispanic	1 (2.8)	1 (12)	2 (1.6)
	Non-Hispanic	31 (86.1)	83 (96.5)	114 (93.4)
Education level	Bachelors	22 (61.1)	41 (47.7)	63 (51.6)
	Masters	14 (38.9)	42 (48.8)	56 (45.9)
	Higher degree	0 (0)	3 (3.5)	3 (2.5)
Diagnosed asthma	Yes	8 (22.2)	10 (11.6)	18 (14.8)
Allergies	Yes	21 (58.3)	43 (50.0)	64 (52.5)
Allergy types	Mold	11 (30.6)	19 (22.1)	30 (24.6)
	Dust mites/ dust	11 (30.6)	23 (26.7)	34 (27.9)
	All pollen[d]	13 (36.1)	29 (33.7)	42 (34.4)
Smoking history	Never	29 (80.6)	60 (69.8)	89 (73.0)
	Former	7 (19.4)	23 (26.7)	30 (24.6)
	Current	0 (0)	3 (3.5)	3 (2.5)
Any home exposures[e]	Yes	36 (100.0)	82 (95.4)	118 (96.7)

[a]Eligible participants included consented, full-time teachers who completed the enrollment survey.

[b]Total does not add up to 100% because some participants identified with >1 race.

[c]Missing, n=6 participants.

[d]"All pollen" category includes relevant responses under "Other allergens."

[e]"Any home exposures" includes indoor smoking, indoor pets, carpeted bedroom, wood burning stove or fireplace, gas heating or stove, and indoor sightings of roaches, rodents, or mold.

TABLE 2

REPORTED ASTHMA, COLD, AND ALLERGY SYMPTOMS BY PHASE

Symptoms	Phase 1		Phase 2		Total	
	Number of Participants (n=36)	% Symptomatic person-days (n=1634)	Number of Participants (n=86)	% Symptomatic person-days (n=8569)	Number of Participants (n=122)	% Symptomatic person-days (n=6935)
Any asthma-like symptoms[a]	15	10.83	34	4.50	19	3.01
Wheezing	7	3.37	20	1.77	13	1.40
Chest pain	4	0.86	12	0.78	8	0.76
Tightness in chest	6	3.86	18	1.77	12	1.21
Shortness of breath	6	3.61	19	2.36	13	2.06
Dry cough	11	5.32	15	1.40	4	0.48
Any cold/allergy symptoms[a]	30	26.68	94	20.95	64	19.6
Productive cough	13	9.12	39	5.03	26	4.07
Itchy eyes	16	6.98	46	5.80	30	5.52
Itchy, scratchy throat	15	6.24	45	3.73	30	3.14
Stuffy nose	26	14.32	86	13.55	60	13.4
Runny nose	19	13.40	64	9.71	45	8.84
Sneezing	15	9.36	59	8.46	44	8.25
Sore throat	19	4.41	58	4.08	39	4.01

*Percent of missing person-days was 7.34 for any asthma-like symptoms (Phase 1=8.32; Phase 2=7.11) and 7.67 for any cold/ allergy symptoms (Phase 1=8.75; Phase 2=7.41).

TABLE 3

RISK RATIOS (95%CI) FOR THE ASSOCIATION BETWEEN CLASSROOM HUMIDITY EXPOSURE ON DAYS PRESENT AND TEACHERS' ASTHMA-LIKE SYMPTOMS[a]

Humidity	Comparison	Person-Days (N)	No Lag[b]	One-Day Lag[b]	Two-Day Lag[b]
Relative	<30%	27484	1.05 (0.78, 1.42)	1.17 (0.86, 1.58)	0.84 (0.62, 1.15)
	30-50%	89485	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
	>50%	54411	1.09 (0.85, 1.38)	1.08 (0.84, 1.38)	1.09 (0.84, 1.41)
Absolute	1g/m^3 increase	171380	0.95 (0.89, 1.03)	1.00 (0.93, 1.07)	1.03 (0.96, 1.10)

AH=Absolute humidity. CI=Confidence interval. RH= Relative humidity. RR=Risk ratios.

[a]Risk ratios were adjusted for outdoor temperature, based on inclusion criteria of ≥5% change in estimate. We estimated RR using a modified Poisson regression approach for correlated binary data, clustered by participant (i=122) with an autoregressive correlation matrix.

[b]Among those present in the school building on the day of humidity measurement. For one and two-day lags, RH and AH observations on days, t-1 and t-2 respectively, were modeled with symptoms measured on day, t.

TABLE 4

RISK RATIOS (95%CI) FOR THE ASSOCIATION BETWEEN CLASSROOM HUMIDITY EXPOSURE ON DAYS PRESENT AND TEACHERS' COLD AND ALLERGY SYMPTOMS[a]

Humidity	Comparison	Person-Days (N)	No Lag[b]	One-Day Lag[b]	Two-Day Lag[b]
Relative	<30%	27484	1.00 (0.90, 1.12)	1.00 (0.89, 1.12)	1.03 (0.94, 1.14)
	30-50%	89485	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
	>50%	54411	1.00 (0.92, 1.09)	1.02 (0.93, 1.12)	1.02 (0.92, 1.13)
Absolute	1g/m^3 increase	171380	1.00 (0.97, 1.02)	1.00 (0.98, 1.03)	1.00 (0.98, 1.03)

AH=Absolute humidity. CI=Confidence interval. RH= Relative humidity. RR=Risk ratios.

[a]Results were estimated using a modified Poisson regression approach for correlated binary data, clustered by participant (i=122) with an autoregressive correlation matrix. No covariates met the inclusion criteria, so unadjusted risk ratios are presented.

[b]Among those present in the school building on the day of humidity measurement. For one and two-day lags, RH and AH observations on days, t-1 and t-2 respectively, were modeled with symptoms measured on day, t.

TABLE 5

RISK RATIOS (95%CI) FOR THE ASSOCIATION BETWEEN ADJUSTED CUMULATIVE CLASSROOM HUMIDITY EXPOSURE AND RESPIRATORY SYMPTOMS OF TEACHERS ON THE SEVENTH DAY[a]

Symptoms	After 5 g/m Increase in Cumulative Average AH	After 5 Days of <30% vs. 30-50% RH	After 5 Days of >50% vs. 30-50% RH	After 5 Days of >60% vs. 30-60% RH
Asthma-like[b]	0.85 (0.48, 1.51)	1.26 (0.73, 2.17)	1.27 (0.81, 2.00)	0.92 (0.28, 3.01)
Cold/allergy	0.87 (0.68, 1.11)	1.11 (0.90, 1.37)	1.06 (0.82, 1.37)	0.95 (0.60, 1.50)

AH=Absolute humidity. CI=Confidence interval. RH=Relative humidity. RR= Risk ratios.

[a]Results were estimated using a modified Poisson regression approach for correlated binary data, clustered by participant (i=122) with an autoregressive correlation matrix. Exposure to classroom was assessed using cumulative presence in school on the previous 7 days, adjusted for “dayworked.” If dayworked=0, we coded RH as missing. Since we considered teachers not present on weekends, the maximum number of days present was 5.

[b]Asthma-like symptom models were adjusted for outdoor temperature (°C).