FREE TO BREATHE, FREE TO TEACH: INDOOR AIR QUALITY IN SCHOOLS AND RESPIRATORY HEALTH OF TEACHERS

Kim Ann Gaetz

A dissertation submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Epidemiology in the Gillings School of Global Public Health.

Chapel Hill
2014

Approved by:

David Richardson

David Lipton

Stephen Marshall

Steve Wing

Michelle Hernández

© 2014
Kim Ann Gaetz
ALL RIGHTS RESERVED

ABSTRACT

Kim Ann Gaetz: Free to Breathe, Free to Teach: Indoor Air Quality in Schools and Respiratory Health of Teachers
(Under the direction of David Richardson)

Controlling indoor dampness can be challenging for schools, especially in the warm and humid southeastern United States. Failure to control indoor humidity directly impacts air quality, and indirectly may lead to problems with mold and dust mites and infestations by roaches and rodents. These potential allergens can trigger adverse health effects in school building occupants, especially in teachers who may work in one building for many years. Our first aim was to describe the problem of relative humidity (RH) control in schools and to examine associations between building-related factors and RH control. Our second aim was to estimate the risk of asthma and cold/allergy symptoms among teachers exposed to high (>50%) and low (<30%) compared to recommended (30-50%) humidity levels in their classrooms. We measured daily symptoms from a cohort of 122 teachers from 10 schools in two NC school districts. We logged RH every 15 minutes in 134 classrooms (n= 852,519 observations) and recorded information on building-related factors. Polytomous logistic regression was used to quantify associations between these structural factors and average daily RH below, within, or above the recommended level of 30-50%. Symptom data were analyzed using modified Poisson regression models for correlated binary outcomes, clustered by classroom. The odds of high RH (>50%) were 6.64 (3.96, 11.12) times higher for classrooms with annual vs. quarterly heating, ventilating, and air conditioning (HVAC) system maintenance. The odds of high RH were also 3.07(2.04, 4.63) times higher for classrooms in buildings with an economizer vs. none. During occupied time periods, the odds of high RH in classrooms with programmed thermostat setbacks were 3.48 (1.89, 6.38) times the odds of those with no setbacks. Among those present in the school building, the risks of asthma symptoms were slightly elevated for participants in classrooms with low vs. recommended RH [risk ratio (RR)=1.09 (0.84, 1.35)] or high vs. recommended RH [RR=1.09 (0.84, 1.35)]. Atopy at baseline and presence in the school building were independently associated with asthma and cold/allergy symptoms. These findings suggest practical remedies for poor air quality in schools and highlight the effects of indoor air quality on teachers' health.

--To all of the people who have supported me along the way (most especially, my husband, Sam Gaetz), to all of the people who inspired me but are not around to see this completed (Bob Millikan, Gwen Simpson, DJ Lewis, Chris Ortega, Jean Angelon, and Gemma Rapaglia), and to God, who made this dissertation possible during the times when it seemed most improbable.

ACKNOWLEDGEMENTS

The people and organizations that have supported and helped me to reach this goal are too numerous to list. Most importantly, I am immensely grateful for the mentorship and friendship of Dr. David Richardson, who could teach me epidemiology methods, work-life balance, and encourage me forward in my career, all over a cup of coffee. Dr. Karin Yeatts believed in this project idea and was essential to the grant writing, project development, and implementation. Thank you to Drs. Steve Wing, Steve Marshall, Michelle Hernandez, and David Lipton for helping me to shape this dissertation into something (hopefully) useful and interesting.

When I was just a fledgling biologist, Drs. Mike Stuart, Betsy Wilson, Tim Forrest, and Jim Petranka taught me scientific integrity, sound research methods, and the importance of creating a career path that is uniquely your own. Pat Ward sparked my early interest in science and suggested this research topic. Edna Hensey, Tamara Edmonds, Carolyn Jackson, Pat Ward, Rozanne Farrell, and Teresa Edwards provided thoughtful reviews of Phase 1 study materials and procedures. My research assistants, Jenna Hargens, Bryce Koukopoulos, Petra Sander, John Buckley, David Kleckner, and Annah Wyss helped with data collection, programming, organization, and reporting. The epidemiology department support staff patiently guided me through the dissertation and budgeting processes. My dissertation support group and MSPH cohort friends were generous with advice, support, motivation, and study breaks. Above all, I would like to thank my study participants and school staff members without whom this research would not have been possible.

Lastly, I extend a huge “thank you” to all of these funders who believed in this work. This research was supported in part by a grant from the National Institute of Environmental Health Sciences (P30ES010126) through the Center for Environmental Health & Susceptibility (CEHS), University of North Carolina (UNC) - Chapel Hill. Additional funding was provided by the North Carolina Translational and Clinical Sciences Institute (NC TraCs) 10K Pilot Project Award Number UL1RR025747 from the National Center for Research Resources, the National Institute of Occupational Safety and Health (NIOSH) Training Grant, the Environmental Protection Agency (EPA) Science to Achieve Results (STAR) Fellowship, and the NC Public Health Association (NCPHA) Scholarship.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

ACT	Asthma Control Test™
AHEC	Area Health Education Centers
ALA	American Lung Association
ANOVA	Analysis of variance
AR	Autoregressive
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AAWSS	Average Area Water Stain Score
β	Beta
BRFSS	Behavioral Risk Factor Surveillance System
cfm	Cubic feet per minute
CI	Confidence interval
^{o}C	Degrees Celsius
DAG	Directed acyclic graph
EPA	Environmental Protection Agency
^{o}F	Degrees Fahrenheit
GEE	Generalized Estimating Equation
$>$ / $\geq$	Greater than/ greater than or equal to
HVAC	Heating, ventilating, and air conditioning
IAQ	Indoor air quality
ICC	Intraclass correlation coefficient
ID	Identifier(s)
inHg	Inches of mercury

IP	Internet protocol
IPM	Integrated pest management
IRB	Institutional Review Board
< / ≤	Less than/ less than or equal to
LEED	Leadership in Energy and Environmental Design
µg	Micrograms
NC	North Carolina
NHANES	National Health and Nutrition Examination Survey
NIOSH	National Institute for Occupational Safety and Health
OAS	Open Airways for Schools
OR	Odds ratio
%	Percent
Pr	Probability
RH	Relative humidity
RR	Risk ratio
SD	Standard deviation
SE	Standard error
spp.	Species (plural)
UNC	University of North Carolina
WHD	Weekly Health Diary

1. BACKGROUND AND REVIEW OF THE LITERATURE

1.1. INTRODUCTION

The “Free to Breathe, Free to Teach” study examined building-related factors influencing indoor dampness, as quantified by classroom relative humidity (RH), with the goal of providing recommendations for classroom humidity control. Classroom RH data were also paired with teachers’ respiratory symptom data to assess whether classroom humidity levels were associated with teachers’ reported symptoms.

The following is a review of the recent literature published in English from the past 20 years. I searched PubMed and Web of Science using the following Boolean search terms and combinations of these terms: mold growth relative humidity NOT food, low relative humidity AND (schools, employees, educational, school, teachers, health), dry air teacher*, teacher OR school staff OR school employee OR educators AND (allergy, asthma, sick building syndrome, mold, humidity, relative humidity, dampness, moisture, occupational asthma, work-related asthma, indoor air quality), allergy determinants AND (humans, review), indoor relative humidity AND (school, classroom), occupational asthma AND educational industry; mold OR dust mites AND (life cycle, reproduction, survival, propagation). Original articles or reviews were used depending on availability.

1.2. INDOOR AIR QUALITY FACTORS RELATED TO RELATIVE HUMIDITY

1.2.1. Overview of the Problem of Indoor Dampness

In 2007, the World Health Organization (WHO) convened a panel of experts to review the scientific evidence of the respiratory health effects of indoor dampness. The panel concluded that indoor dampness is a sign of poor ventilation and also a cause of indoor air quality (IAQ) problems, including growth of mold, proliferation of dust mites and other vermin, and increases in chemical emissions (1).

Among studies on residential dampness, a meta-analysis found increased odds of bronchitis [odds ratio (OR) =1.45 (1.31, 1.59)] and other respiratory infections [OR=1.44(1.32, 1.59)] in homes with dampness or mold compared to those without dampness or mold (2). Children living in homes with surface dampness had 1.76 (1.06, 2.92) times the odds of developing allergic rhinitis compared to those in homes without surface dampness (3). Cumulative lung function decline in women with a home dampness score >0 was -2.25 (-4.25,-0.25) mL/ year more than the lung function decline in woman with no home dampness (4).

In workplace health hazard evaluations, the National Institute for Occupational Safety and Health (NIOSH) found that water damage was among the most commonly reported building issues related to indoor air quality (IAQ) (5). Several IAQ studies have focused on water damage and dampness in schools, suggesting that educational employees may be at higher risk of receiving these particular exposures than other non-industrial workers (5-20). In our study, indoor dampness in schools was quantified by classroom relative humidity (RH), which measures the amount of water that air can hold without condensing at a given temperature.

1.2.2. Mold

Mold is thought to cause health problems such as asthma, allergies, and hypersensitivity pneumonia; however, no clear mechanism or threshold has been found for these health effects attributed to mold exposure (1, 9, 10, 21, 22). It is speculated that allergenic components of mold include proteins from mold spores and β-d-glucans from hyphal cell walls which have been shown to produce an increase in tracheal neutrophils in rats (22, 23). A review of the literature on the health effects of mold growth found that not all people who develop respiratory symptoms after indoor mold exposure test positive for specific IgE to fungal allergens. Possible non-allergic reactions to mold may occur due to the off-gassing of microbial volatile organic compounds (VOCs) which act like chemical irritants in the stimulation of trigeminal, glossopharyngeal, and vagus nerves (23). Among a sample of patients newly evaluated for occupational asthma (OA), 20% of those with probable OA had a positive mold allergy skin test compared to 9.6% of those with unlikely OA (24). In a separate study, 67% of office workers with sick building syndrome symptoms had IgG but not IgE antibodies to one or more molds, indicating an infection rather than allergic response (25).

Quantification of relevant mold exposure is difficult since both mold spores and hyphal fragments can be allergens (22). Spores and fragments can be found both indoors and outdoors. Thus, indoor mold test results should be compared to outdoor levels of mold. These tests are most useful when paired with a thorough investigation of the premises to find the source of the moisture problem (26-28). The exact mold species which cause health effects may also vary from individual to individual, depending on susceptibility (1, 28). Mold genera commonly studied in relation to health effects are *Aspergillus*, *Cladosporium*, *Penicillium*, *Streptomyces*, and *Alternaria* (25, 29, 30).

There is no single sampling method that is both specific and robust enough to reliably detect mold growth. Mold can be measured through swabbing of mold growth, passive sampling of mold that settles on a petri dish, or vacuum sampling of dust or air (31). However, mold inspections and testing have no standard methods and no widely recognized credentials for investigators, leading to much variation in the quality of inspections and tests. (32). In addition, since the dose-response relationship between mold exposure and respiratory health effects is largely unknown, the discovery of mold growth during the environmental assessment of a building can not necessarily predict occupant symptoms (32).

Though we know that stagnant, moist air encourages mold growth, the literature on indoor dampness is conflicted as to which indices of dampness and measures of mold can reliably relate qualitative signs of mold growth to human health effects (4, 12, 30). Park, et al. created an Average Area Water Stain Score (AAWSS) which was higher in rooms with mold odor, visible mold, or damp/wet material than in rooms without signs of mold or dampness. The AAWSS and visible mold more consistently predicted respiratory symptoms in the employees of those buildings than moldy odor or other moisture-related indices, possibly indicating a psychosomatic effect of seeing the allergen. (21). Area of mold growth as an index of exposure does not give information about mold spore releases, mycotoxins, or microbial metabolites that may cause health effects as well (33). Thus, some researchers have suggested that mold odors may be better indicators of actual mold growth than visible signs of mold since mold may be hidden and water stains may be mistaken for mold growth by building occupants. Jones, et al. found that measured viable mold levels were significantly higher in homes where participants reported mold odors (29). The European Community Respiratory Health Survey (ECRHS) II found little correlation between self-reported dampness score and self-reported mold score among participating homes (4).

Mold growth is a sign that the building is not being properly cleaned and maintained and has some prolonged excess moisture source (1, 8). To establish growth, mold needs more bioavailable water in cold compared to warm conditions and nutrient poor (clean and rot resistant) compared to nutrient rich conditions (34). In laboratory conditions, mold takes at least one week to grow if RH is kept below 95%; however, in the field, mold may grow more quickly if critical moisture thresholds are exceeded for long enough (34, 35). These moisture thresholds differ depending on the climate, the mold species, and the surface material in question (34-36). Most porous materials, such as gypsum board, must be fully dried or replaced within 48 hours of water damage to prevent mold growth (37, 38).

Even in the absence of direct water damage, mold can grow at high RH levels. An observational study of fungi in office buildings found that Factor 1 fungi (including *Alternaria*, *Aspergillis*, *Cladosporium*, and *Penicillium spp.*) were positively correlated with RH >35% (39). Another study found that levels of viable mold were higher in homes with RH above compared to below 50% (29). Since RH levels that trigger mold growth have been determined, we quantified RH levels rather than mold growth, since the interpretation and practical implications of RH control are more clearly understood.

1.2.3. Dust Mites

Dust mites maintain water balance mainly by passive absorption of water vapor from the air and transpiration through their skin. The lowest relative humidity (RH) that dust mites can maintain equilibrium was originally estimated to be about 70% (40). More recently however, Arlian et al. found that the half-life for desiccation of house dust mites (*Dermatophagoides* *farina*) at 45% RH was 11.5 weeks compared to 86.3 weeks at 50% RH (41). In the former study, dust mites died within 5 days under laboratory conditions at 22.5% RH. Dust mites consumed 0.17µg of yeast at 22.5% RH and 0.48µg of yeast at 65% RH compared to 1.08 µg of yeast at 75% RH, indicating lower activity rates of mites at lower RH (40).

Carpets may be reservoirs for dust mite and mold growth (5, 42). Reductions in allergens and dust mite levels were seen in the bedroom carpet, but not in mattresses or sofas of houses that were randomly assigned to dehumidification by mechanical ventilation compared to those with no ventilation (43). However, in an inner city household study, a null or slightly inverse relationship between RH and allergen levels was found in an analysis of the dust samples (44).

Fabrics in classrooms may be reservoirs for indoor allergens such as dust mites, but preventative measures, such as washing the curtains once a year, may significantly reduce airborne, allergen concentrations (45, 46). Integrated dust mite control procedures include removing dust and potential habitats and introducing protective barriers such as plastic casing on upholstery to prevent dust collection and reduce allergen levels. However, a review of dust mite interventions found that encasing children's bedding was the only dust mite control procedure out of these with strong clinical evidence to support its efficacy in reducing symptoms (47).

1.2.4. Chemical Emissions

Besides changing rates of microbial growth and transmission, dust particle suspension in air and emissions of chemical pollutants from materials in the building may also be affected by RH (27, 44, 48). For example, an environmental field study found that formaldehyde concentrations from off-gassing in test houses increased when RH was increased and that the concentration increased faster when both temperature and RH were simultaneously increased.

When the indoor climate shift from the heating to cooling season was simulated in test houses, there was a 2 to 4 fold increase in formaldehyde concentrations (49).

1.2.5. Indoor Pests

Rodents and roaches are attracted to damp environments and leave behind allergens in school buildings (27, 50). Pest control is challenging in schools due to multiple sources of food and moisture attracting the pests, poor sanitation and maintenance of school buildings, and the sensitivity of children to pesticides (27, 51). In a study of allergen seasonality, cockroach allergens were highest in the winter since roaches were attracted to the heat and condensation inside buildings (44). Integrated pest management (IPM), which in itself may improve indoor air quality by reducing the use of pesticides, is a strategy which controls pests by reducing their access to food, shelter and water; sealing routes of entry into the building; trapping pests; and applying pesticides sparingly (27). Since it is the current best practice for pest control, all NC public schools were legally required to implement an IPM program by October 1, 2011 (52).

1.3. EFFECTS OF INDOOR DRYNESS

Low RH can cause drying and irritation of skin and mucous membranes, including eyes and nasal passages, which may increase disease transmission (53, 54). In guinea pigs, influenza virus droplet transmission was highest at low relative and absolute humidity levels (55, 56). In humans, increases in influenza mortality correspond to periods of low RH (57). Research on coronavirus survival on hard surfaces suggests viruses have better survival at both 20 and 80% RH than at 50% RH (58). However, in a study of common colds among students in crowded dormitories, RH did not seem to influence infection rates or duration (59).

1.4. DETERMINANTS OF INDOOR RELATIVE HUMIDITY

Outdoor humidity, like temperature, exhibits seasonal and daily variation. Since cool air is able to hold less moisture than warm air, outdoor RH tends to be highest in the early morning (the coolest time of day) and lowest in the afternoon (the hottest time of day). Outdoor humidity and temperature affect indoor humidity and temperature by moving air into buildings via the "stack effect." The "stack effect" refers to the upward movement of warm air, which causes lower pressure on the lower levels of a building and allows air to enter through intake valves, open windows, and other openings in the building envelope (60). Thus, a tall square building in a cold climate is likely to have greater infiltration than a short square building in the same outdoor conditions. A low-rise school can still have issues when there is a vented attic where temperature differences serve to induce air flow.

School buildings are typically temperature controlled, with a "cooling season" in the summer and a "heating season" in the winter. Unfortunately, air conditioning systems used in most American schools are not designed specifically to control humidity, although some cooling mechanisms remove moisture from the air while cooling it (61, 62). As the temperature of incoming air moving across cooling coils is lowered below the dew point, water condenses out of the air stream and onto the coil. Thus, the exiting air stream is at a lower temperature and humidity ratio than the incoming air stream. (Humidity ratio here is defined as the mass of water vapor present in moist air compared to the mass of the dry air.) Cooling to condense water from the air is called latent cooling or dehumidification. Another method of dehumidification is to add a desiccant to the air conditioning system (63). A reduction of humidity, with reductions in allergens and dust mite levels in the bedroom carpet, was seen in the bedroom of houses with mechanical ventilation with heat recovery (MVHR) systems added compared to those with no ventilation (43).

Though still debated, conventional wisdom suggests that the building envelope permeability may also be influenced by the age of the building due to the type and quality of insulation and air seals, the choice of building materials, and the quality and frequency of maintenance (64). Poorly insulated surfaces can allow condensation to form during periods of extreme temperatures due to the temperature differential between outdoor and indoor air (65). Regular condensation can lead to mold growth and water damage.

Besides condensation from improper insulation, many building maintenance problems may cause excess moisture in schools including inadequate ventilation, flooding, leaks, spills, and/ or improper drainage (27). Resource-poor schools may forgo necessary repairs and maintenance and are often located in areas at risk for flooding (66). In addition to regularly cleaning, repairing, and maintaining all buildings, the United States Environmental Protection Agency (US EPA) recommends that schools should keep indoor RH levels between 30-50% to control mold, dust mites, and pests (51). Since in North Carolina, counties have the responsibility of maintaining school facilities, the tax base or the socioeconomic status of the school's community may influence the school's ability to meet these standards for moisture control (67).

Relative humidity is typically higher in rooms with reduced airflow, due to water vapors from people breathing in the room (68). Given the same rate of airflow and climate, a crowded room will have a higher RH than a room with only a few people. For example, classrooms of 20-40 students per room would most likely have higher RH than an office of the same size that contains only 5-10 adults. In addition, Bayer, et al. found that schools with active humidity systems had both lower humidity and higher ventilation rates (15cfm/person) compared to schools without active humidity systems (5cfm/person)(20).

1.5. ASTHMA

1.5.1. Definitions

Asthma is a common, chronic illness in which the airflow to the lungs is restricted because of inflammation and bronchoconstriction. Primary symptoms include wheezing, shortness of breath, dry cough, and night wakening due to inability to breathe (47).

The British Occupational Health Research Foundation recognizes two types of work-related asthma. Occupational asthma is defined as asthma caused by workplace exposure to dust, fumes, or vapors. Work-aggravated asthma, on the other hand, is when a worker’s pre-existing asthma or newly diagnosed asthma (not initiated by workplace exposure) is exacerbated by “non-specific” factors in the work environment such as cold or dry air (69). Due to the short follow-up time of this study, work-aggravated asthma was the primary focus.

1.5.2. Risk Factors for Developing Asthma

Several risk factors influence a person’s susceptibility to developing asthma when exposed to asthma triggers. Primary prevention of new asthma cases involves limiting exposure to causative agents (70). Development of asthma is influenced by inherited traits such as airway hyper-responsiveness and inflammation, and gene-regulated responses to immunological challenges. During childhood, males have a higher incidence of newly diagnosed asthma; however, among adults, females have higher current asthma prevalence (47).

Having a body mass index (BMI) >30kg/m^2 is a risk factor both for developing asthma and for having poorly controlled asthma (47). In a cohort of teachers, abdominal obesity strongly influenced the development of adult-onset asthma [OR=2.36 (2.15, 2.59)]. Being either obese or overweight in general was associated with higher odds of having current asthma (defined as at least one urgent visit to the doctor or hospital in the past 12 months) and/or adult-onset asthma especially among teachers who were not overweight at 18 years old (71). Obesity may influence asthma development by promoting inflammation and hyper-responsiveness and by changing lung function and hormonal secretions (47, 71).

Smoking is also a risk factor for asthma development and increased asthma severity (52, 51, 49). Smokers have more frequent asthma exacerbations and more rapid decline in breathing capacity than non-smokers and may have a decreased response to certain asthma medications. Exposure to tobacco smoke during infancy is a risk factor for developing wheezing later in childhood (47). In a study of asthmatic children in North Carolina, both environmental tobacco smoke and personal smoking were shown to be risk factors for current wheezing (72).

Other early childhood exposures have been shown to increase the likelihood of developing asthma later in life. Current evidence suggests that sensitization to cockroach allergens is an important risk factor; however, the roles of early exposure to other allergens such as dust mites and pet dander are still debated. Other potential risk factors include having respiratory infections during infancy, being raised in a polluted environment, and being formula rather than breast-fed (47). A conflicting study comparing the indoor home environments of asthmatic to non-asthmatic children found no significant differences between sources of pollutants, actual measured pollution concentration in bedroom, indoor allergen level, or lifetime pollutant exposure (73).

According to the “hygiene hypothesis,” early childhood exposure to crowded conditions and poor hygiene can protect a child against developing asthma by giving the developing immune system infectious agents to attack rather than relatively harmless allergens (74). In North Carolina, middle school students who live near large numbers of beef cattle, several acres of hay, and large numbers of farms had lower asthma prevalence than children living in counties with few farm exposures (75).

Risk factors for adult-onset of asthma include occupational exposures to dusts and reactive chemicals that act as airway irritants and biological allergens that trigger immune responses (47). Reducing exposure to these irritants and allergens can reduce the incidence of occupational asthma (69). Among adult US citizens, other risk factors for having poorly controlled asthma include being African American, having a low income, and having only a high school level education (76).

1.5.3. Prevalence of Asthma and Risk Factors

In 2010, the prevalence of current asthma among North Carolina residents was 7.5% (6.8-8.3%), and 12.6% (11.6-13.7%) of residents had ever been diagnosed with asthma (77). Table 1.1 details the prevalence of asthma and several risk factors for asthma by Area Health Education Center (AHEC) region, as collected by the 2010 NC Behavioral Risk Factor Surveillance Survey (BRFSS). During the 2010-2011 academic year, our study sites were part of the Greensboro and Coastal AHEC regions. Current and ever asthma prevalence were higher among residents of these regions compared to the state overall. Over a quarter of the population was reportedly obese and almost a fifth of the residents were current smokers at the time of the survey (77).

TABLE 1.1. ASTHMA AND RISK FACTOR PREVALENCE (77)

	AHEC* Region			
	Greensboro		Coastal	
Attribute	Prevalence	95% CI**	Prevalence	95% CI**
Ever Diagnosed with Asthma	13.9	11.6-16.6	13.7	9.0-20.5
Current Asthma	8.7	6.9-11.0	8.2	4.4-14.6
Current Smoker	18.7	16.0-21.7	18.8	13.4-25.9
Obese	27.2	24.4-30.3	29.2	22.9-36.3

*AHEC= Area Health Education Centers
**CI=Confidence Interval

1.5.4. Common Asthma Triggers

Asthma "triggers" are factors which cause asthma symptoms to develop in sensitive individuals, including aeroallergens, viral infections, exercise, irritants, some medications, and gastroesophageal reflux (47, 70). Once a person develops clinical asthma, tertiary prevention involves both treatment to control asthma symptoms and avoidance of asthma triggers to minimize the frequency of episodes (70).

Molds and mildew have been associated with both asthma exacerbations and new cases of occupational asthma (24, 47). Ability to culture *Aspergillis* and *Streptomyces spp*. from classrooms in Malaysia was positively associated with asthma symptoms and diagnoses among students in those classrooms (30). Among children in Buffalo, NY with no family history of asthma, asthma cases had 6.11 (90% CI: 1.37, 27.19) times the odds of exposure to *Aspergillis* than controls (29). In NC, 74% of asthmatic children's homes had an Environmental Relative Moldiness Index (ERMI) score above the median of the control homes based on dust samples (78). Among office workers previously undiagnosed with asthma, visible mold was associated with an increase of wheeze and chest tightness (21).

Dust mites and pet dander are also common asthma triggers (47). Their allergens accumulate in upholstery, carpets, and other fabrics (22, 46, 51). However, there is little evidence to support pet removal as an effective measure for reducing asthma symptoms, possibly since pet dander is extremely difficult to remove from the indoor environment entirely (47).

Dusts from chalk and vapors from dry-erase markers, furniture and cleaning products may trigger asthma exacerbation or other respiratory irritations among school building occupants. Art and science classrooms, in particular, are full of materials that produce dusts and fumes (50, 51). Workers who have high levels of exposure to dust, gas, and fumes were found to have higher odds [OR= 3.1 (1.9-5.1)] of severe asthma exacerbation than those who were unexposed or less exposed (79).

In addition to the indoor environmental irritants and allergens described above that may trigger exacerbations, there are also emotional triggers of asthma such as stress and anxiety (47). Among low-income parents of asthmatic children, those who had low feelings of neighborhood collective efficacy were more likely to have children who wake up at night with asthma and have uncontrolled asthma (80). Increased housing stress among low income children was also associated with poor asthma control (81). Stress may be linked to asthma onset and exacerbation by changing immunological responses to foreign bodies and causing health compromising behaviors (81). Teaching is a highly stressful job (82). Increased stress was associated with increased teacher absences in many studies, though the exact reasons for these absences (i.e. illness versus personal leave) were undetermined in that particular study (83).

Ambient temperature and humidity have been linked to asthma exacerbations. Exercise-induced asthma can occur after exercising in cold, dry air (47, 70). Changes in temperature and humidity may cause inflammation or hyper-responsiveness or may influence the airborne concentrations of known asthma triggers such as pollutants, molds, and pollens (47, 84). A Taiwanese study of asthma hospitalizations found that rainfall was negatively associated with asthma admissions in children (85). May, et al. found that asthma-related emergency department visits in Washington, DC were positively correlated with average relative humidity (correlation coefficient=1.528 [0.296-2.760]) and tree pollen counts (correl. coef. =0.458 [0.152-0.765]). In the same study, asthma hospital admissions were negatively correlated with average temperature (correl. coef. = -0.557 [-1.052 to -0.061]) after adjustment for particulate matter (86).

Seasonality of asthma differs by location and outcome. In five NC urban areas, the greatest numbers of asthma hospital admissions occurred in the fall and winter with the least admissions in the summer (87). A statewide NC study found that asthma-related emergency department visits were positively associated with outdoor temperature in the winter and summer and negatively associated with temperature in the spring (84).

Air pollutants, which are affected by weather patterns, have also been linked to an increase in asthma exacerbations on a population level (47). Ozone and PM_{10} were correlated with increased asthma hospitalizations among Taiwanese children (85). Though airborne allergens such as pollen and fungi independently increase asthma hospitalizations, PM_{10} may be an important modifier of the relationship between asthma hospitalizations and aeroallergens. Air pollutants may act by damaging pollen grains, causing them to be more easily shed, and by damaging human airways, making them more susceptible to the effects of pollution (86, 88). Carbon monoxide has also been shown to increase the effect of fungi on asthma hospitalizations in Canada (88). In North Carolina, dry tropical, dry moderate, and moist tropical air masses were associated with high ozone levels in a study of five metropolitan areas, including our study sites. The hottest and most humid days during moist tropical air masses were associated with statistically significant increases in current hospital admissions for asthma per 10 ppb increase in ozone. However, under dry moderate air masses, there was a negative association between ozone and hospital admissions. Under the dry tropical air mass, increases in ozone were associated with statistically significant increases in asthma hospital admissions with lags of one to five days (87).

1.6. ALLERGY DETERMINANTS

Allergies develop when susceptible individuals are exposed to seemingly harmless substances which illicit a hypersensitive immune response. Repeated exposures to allergens trigger the body to mount increasingly greater and more sensitive responses to these invaders. Allergens may trigger immediate recognition from specific IgE antibodies which activate releases of histamines from mast cells and basophils and/or there may be a more gradual attack from the non-specific T-cells (89). Since mast cells are concentrated in the skin, respiratory and digestive systems-- the most likely points of entry for foreign bodies—inflammation occurs primarily in these systems (90).

Typical allergy symptoms involve irritation of the mucous membranes and increased mucus production including watery, itchy eyes; runny nose; sneezing; and itchy throat/ cough. Dermatologic reactions to allergens include swelling and itching, eczema and hives. Asthma symptoms- wheezing, chest tightness, and trouble breathing- can also be allergic responses (89).

Allergy symptoms may develop in stages after exposure to an allergen. A person who is allergic to the substance may experience allergy symptoms as quickly as seconds after exposure. After 4-8 hours, more symptoms may develop. Repeated exposure to an allergen may cause chronic inflammation and thus chronic symptoms (89).

In the United States, over half of the population is likely reactive to at least one allergen. Common allergens include pollen, dust mites, mold, and certain types of food and drugs (89).

Children whose parents have allergies are more likely to develop an atopic response to airborne allergens than children of non-atopic parents (91). Infants with atopic dermatitis often develop other allergic syndromes later in life (89). Women and residents of urban areas are more likely to develop allergies than men and residents of rural areas (89). In urban areas, exposure to pollutants such as PM_{10} and carbon monoxide may increase the immune response to allergens by damaging the mucous membranes, priming them for allergen entry (88). Reduced exposure to intestinal microbiota may increase the risk of developing intestinal and respiratory inflammation (74). Conversely, there is a large body of evidence supporting the "hygiene hypothesis" which states that exposure in early childhood to a diversity of microbiota such as can be found around farm animals is protective against development of allergies later in life (74, 75, 91).

1.7. INDOOR DAMPNESS AND RESPIRATORY HEALTH

1.7.1. Proposed Biological Mechanisms

The following mechanisms have been proposed to explain how indoor dampness affects respiratory health: increased survival of viruses (at 80%RH); immune responses to increased numbers of allergens from mold and dust mites; pathologic responses to mycotoxins or β1-3-D-glucans; irritation of mucous membranes by VOCs (volatile organic compounds) from paint, solvents, and petroleum product emissions; irritation of mucous membranes by microbial VOCs from mold and bacteria; and direct reaction to humidity (23, 58, 92).

Using a guinea pig model to study inhaled droplet influenza transmission, Shaman and Kohn found evidence that viral transmission had an inverse relationship with relative and absolute humidity. The authors postulated that higher humidity may change droplet size or deactivate viral lipids (56). Research on coronavirus survival on hard surfaces suggests viruses were inactivated the fastest at 50% RH at room temperature (20^{o}C) and were potentially infectious for longer at 20 and 80% RH (58). *In vitro* laboratory studies found greater survival of rhinoviruses, a group of viruses that cause the common cold, at high (80%) compared to low (20%) and medium (50%) RH (93, 94). Therefore, both excessive moisture and excessive dryness may increase upper respiratory infection transmission.

Allergic sensitivity from repeated exposure to mold is the mechanism most often discussed in studies of dampness and health (22, 23, 25, 44, 78, 95-100). In North Carolina, the homes of asthmatic children were found to have higher Environmental Relative Moldiness Index (ERMI) values than the homes surveyed from the general population of NC and the US (78). However, as previously discussed, not all people repeatedly exposed to mold develop symptoms, and not all of those who develop symptoms in the presence of mold test positive for mold-specific IgE (23, 25, 100). Potential non-immune responses include eye, nose, and throat irritation from exposure to mycotoxins or fragments from mold hyphae (β1-3-D-glucans), although the literature has been conflicting as to the potential for these agents to cause health issues (1, 23, 100). Another possibility is that some health effects are due to irritation from mVOCs (microbial volatile organic compounds) emitted by molds; however, there is insufficient epidemiologic evidence of this mechanism (1, 23).

The effects of dampness and molds on respiratory health have been assessed in several studies of non-industrial workers (25, 96). Mold growth or dampness was related to rhinitis and nasal symptoms in one review (weighted average OR= 1.84 [1.65, 2.04]). However, the same review found null associations with large confidence intervals for other respiratory symptoms, making conclusions uncertain (25).

In addition to potential microbial causes of symptoms associated with excess moisture, dampness may also impact emission rates and concentrations of chemical pollutants in the school environment (27). In two unoccupied test homes, formaldehyde concentrations in the air increased with temperature and humidity and even more rapidly when both parameters were increased. Mimicking the difference between the heating and cooling period, the authors changed the climate from 20^{o}C with 30% RH to 26^{o}C with 60%RH and saw a two to four-fold increase in formaldehyde concentrations (49). Another study of occupied residences found that RH was positively associated with increased particulate matter, even after controlling for air filter use (β=0.011, σ=0.004) (48).

Changes in humidity alone may trigger airway restriction and mucosal inflammation. In one recent study, one and two day lagged changes in atmospheric RH and temperature but not barometric pressure were associated with increases in pediatric asthma admissions to the emergency department, after adjustment for aeroallergens and pollutants (92). A longitudinal study found that children with water damage in the home and moisture on household surfaces had higher odds of having allergic rhinitis both at baseline and follow-up (3). A randomized control trial (RCT) found large improvements in nighttime peak expiratory flow (PEF) for the group of chronic asthmatics randomized to dehumidification by mechanical heat recovery ventilation (MHRV) compared to the control group [mean difference= 24.56 (8.97, 40.15)]. The same study found a non-significant difference in mean morning PEF between the MHRV and the control group [mean difference=13.59(-2.66, 29.84)] (43). In a study of non-industrial workers, building water damage and infrequent cleaning of HVAC cooling coils and drain pans were associated with mucous membrane symptoms and lower respiratory symptoms (96).

Although there is still uncertainty about the biological mechanisms by which indoor dampness is related to health effects, the WHO has concluded that there is sufficient evidence of an association between dampness and respiratory diseases, including asthma, in humans (1). The aim of the "Free to Breathe, Free to Teach" study is not to clarify the biological mechanism by which this relationship occurs. We hope to add to the body of evidence, examining this association in more detail by using a quantitative measure of dampness tied to current engineering standards, for the benefit of developing new recommendations for assessing humidity problems in schools.

1.8. OCCUPATIONAL HEALTH OF EDUCATIONAL EMPLOYEES

In 2010, over 10% of US, non-agricultural employees worked in educational services, and about two-thirds of those employees were in elementary or secondary schools (101). Therefore, indoor air quality issues in schools have the potential to cause health problems for many workers in our country.

1.8.1. Asthma in Educational Services Employees

Asthma is one of the leading causes of absenteeism from school and work (51). Adults who suffer from asthma symptoms are more likely to miss work than those who do not experience asthma symptoms (102). The absence of the regular classroom teacher is detrimental to both teacher and student performance, and substitute teachers are more expensive for the school (83, 102). Therefore, asthma control and management is as important for teachers as it is for students.

Though teaching is normally considered an occupation with few, long-term health hazards, National Health and Nutrition Examination Survey (NHANES) data (2000-2004) revealed that teachers had the highest asthma prevalence of any occupation surveyed [prevalence=13.1% (7.8-21.2)] next to miners (103). A sample of female, fifth through twelfth grade teachers (1999-2001) from three US urban areas had an asthma prevalence of 13.3% for ever diagnosis and 8.8% for current asthma. Both figures were higher than the prevalence among flight attendants in the same urban areas but not statistically different than the general population from the 2000 BRFSS (104). Around the same time period, the California Teachers Study found that 10.9% of teachers had asthma symptoms in the past year, and 7.6% reported asthma symptoms that required medical intervention (71). A study in New Zealand found a higher prevalence of current asthma among those who had ever worked as teachers compared to those who never worked as teachers [POR= 1.3 (1.0–1.8)], especially among those who had worked in secondary schools (105).

Occupational disease surveillance studies suggest that a large proportion of work-related asthma cases in the US are teachers. In California, Massachusetts, Michigan, and New Jersey, 9% of work-related asthma cases were educational services employees, 68.7% of whom were newly diagnosed with asthma (106). In New York state, the most common occupation among work-related asthma cases was teacher (7.3%), and the most frequently cited workplaces among cases were elementary and secondary schools (9.5%) and colleges and universities (3.5%). School exposures that were most commonly posited as asthma triggers were dust, mold, and other indoor air quality issues (107).

1.8.2. Current Evidence on School Dampness and Teachers' Health

Though school employees spend much of the day in schools and typically many years in one building, only 10 studies on mold and water damage in school environments were found which focus on the health consequences for school employees (6-12, 21, 97, 99). Seven of those focus specifically on teachers as participants (6-8, 10-12, 97).

The studies listed in Table 1.2 vary widely in their methods. Rudblad, et al. used nasal histamine challenge tests as a clinical measure of reactivity of teachers who worked for five years or more in a water-damaged versus non-water-damaged school. However, the study had objective exposure measurements only for the water-damaged school (11). Thorn, et al. reported a case study of a teacher with physician diagnosed allergic alveolitis, lung inflammation from repeated exposure to organic dusts or chemicals, who had symptoms only during the school year, while working in a building with a leaky roof and plumbing and no ventilation on nights and weekends (8). Patovirta, et al. studied the effects of remediation of water-damaged buildings on teachers' self-reported symptoms. In the two schools with total remediation, levels of fungi and bacteria were statistically significantly lower after remediation compared to before remediation. However, in the school with only partial remediation, there was a higher level of airborne microbes after compared to before remediation (97). Another study by Patovirta et al. compared self-reported symptoms of teachers in a mold-damaged versus not damaged buildings within the same campus (6). Park, et al. described a NIOSH study of self-reported respiratory symptoms of college employees from water-damaged versus comparison buildings, using a standardized, scored evaluation to create a semi-quantitative exposure index based on area of water stain / mold damage (21). Another NIOSH study by Thomas, et al. looked at the relationship between self-reported respiratory symptoms of employees from a water-damaged versus comparison school, but used mold testing rather than the exposure index and added visual contrast sensitivity testing to the outcome assessment (8). Prompted by a high percentage of teachers with respiratory complaints, Dangman, et al. described the results of a chart review of patients at an occupational health clinic, diagnosed with work-related asthma due to a decrease in peak flow attributed to workplace exposure to dampness and/or mold (10). Ebbehoj, et al. compared health symptoms of female vs. male teachers in water-damaged vs. non-damaged schools with three potential levels of mold exposure. Health outcomes were measured by questionnaire, spirometry, nasal lavage, bronchial challenge, and carbon monoxide diffusion (12). Sahakian, et al. utilized an inexpensive method of comparison between questionnaire data from NHANES respondents (referent) and responses of teachers in damp or moldy schools to the same questions (9).

Two studies had the benefit of both large numbers of participants and a large sample of buildings for comparison (12, 21). Two longitudinal studies had two or three points of follow-up which ranged from one and six years apart (6, 97). Though many studies measured mold and surface moisture, only one group of authors stated that they measured relative humidity (12). The "Free to Breathe, Free to Teach" study adds to this body of literature a prospective cohort study of the impact of longitudinal, classroom, RH levels on incidence of teachers' daily respiratory symptoms for several weeks of follow-up with a fairly large number of participants.

TABLE 1.2. PREVIOUS FINDINGS ON SCHOOL DAMPNESS AND OCCUPATIONAL HEALTH EFFECTS

Reference	Date	Study Type	Sample Size/ Population	Exposure Assessment	Health Effects
Thomas, et al.(8)	2012	Cross-sectional study	205 teachers from two schools	Tested schools using moisture meters and passive and active mold samplers	Teachers in water-damaged vs. comparison school: Higher prevalence of: Visual contrast sensitivity scores below 90% of the general population (Range= 9-29% in damaged school compared to 0-7% in comparison) Asthma exacerbation at work (69% compared to 23%, p=0.02) Cough [PR= 4.16 (2.26,7.68)] Wheezing [PR= 12.13 (2.91,50.62)] Runny nose [PR= 3.87 (1.73,8.62)] Sore/ dry throat [PR=

24

Reference	Date	Study Type	Sample Size/ Population	Exposure Assessment	Health Effects
					1.95(1.04,3.67)] Fever/ sweats [PR= 4.10 (1.40,12.01)] Headache [PR= 1.74 (1.08, 2.81)] Difficulty concentrating [PR= 4.63(1.60,13.44)] Fatigue [PR= 1.78 (1.04,3.03)]
Sahakian, et al. (9)	2008	Cross-sectional study	309 employees from 2 water-damaged schools, A & B, compared to BASE and NHANES III participants	Used reports from environmental consultants to categorize building sections by amount of moisture damage, evidence of dampness, and visible mold present	Crude PR compared to BASE:* Sore/dry throat [A: 2.6(1.88-3.60); B: 3.7(2.52-5.42)] Chest tightness [A: 2.3(1.28-4.10); B: 4.2(2.28-7.74)] Shortness of breath [A: 2.2(1.15-4.15); B: 4.9(2.64-8.94)]

Reference	Date	Study Type	Sample Size/ Population	Exposure Assessment	Health Effects
					Cough [A: 1.9(1.22-2.85); B: 3.1(1.95-5.00)] Wheezing [A: 1.8(0.97-3.49); B: 4.2(2.28-7.74)] Fatigue[A: 0.8(0.58-1.22); B: 2.2(1.62-3.11)] Headache [A: 0.9(0.64-1.30); B: 2.1(1.47-2.87)] Dry or itchy skin [A: 1.3(0.74-2.17); B: 1.9(1.05-3.57)] Adjusted PR compared to NHANES III: Current asthma [A: 1.4(0.81-2.29); B: 2.3(1.32-4.03)]
Dangman, et al. (10)	2005	Chart review, case control	55 teachers from 55 schools	Extracted environmental data from chart reviews on work-place site visits performed by an industrial hygienist, occupational	Teachers in "wet" vs. "dry" schools: Baseline prevalence of asthma slightly higher in wet (24%) compared to

Reference	Date	Study Type	Sample Size/ Population	Exposure Assessment	Health Effects
				medicine physician, or engineer	dry (23%) Higher prevalence of: Diagnosed sinorhinitis (76 vs. 45%, p=0.02) Incident asthma (21 vs. 0%, p=0.03) Granulomatous lung disease (12 vs. 0%, p=0.04) Abnormal X-ray (29 vs. 0%, p=0.07) Symptomatic asthmatics (45 vs. 23%, p=0.07)
Ebbehoj, et al.(12)	2005	Cross-sectional study	522 teachers from 15 schools	Collected airborne and surface dust samples and tested for viable mold cultures; measured temperature, relative humidity, and carbon dioxide	Dose-response comparing low, medium, high concentrations of viable mold: Male teachers: No statistically significant associations found for any

Reference	Date	Study Type	Sample Size/ Population	Exposure Assessment	Health Effects
					symptoms Female teachers: Eye irritation (18.2 vs. 18.2 vs. 27.3%, p=0.21) Nasal irritation (13.6 vs. 20.7 vs. 31.3%, p=0.01) Throat irritation (10.6 vs. 16.7 vs. 23.9%, p=0.04) Headache (4.5 vs. 11.6 vs. 20.9%, p=0.004) Concentration problems (1.5 vs. 2.0 vs. 16.7%, p=0.002) Fatigue (6.1 vs. 10.6 vs.19.4%, p=0.02) Note: after adjustment for potential confounders, associations remained stronger among females than males.

Reference	Date	Study Type	Sample Size/ Population	Exposure Assessment	Health Effects
Park, et al. (21)	2004	Cross-sectional study	393 employees in 13 buildings on one college campus	Created a semi-quantitative index of visible mold and water-damage weighted by standardized inspection results	Higher vs. lower mold exposure score: Chest tightness [OR=2.2 (1.1-4.60)] Shortness of breath [OR=2.5(1.2-5.4)] Nasal symptoms [OR=2.5 (1.3-4.70)] Sinus symptoms [OR=2.2 (1.2-4.1)]
Patovirta, et al. (97)	2004	Intervention	56 teachers from three mold-damaged schools	Inspected visually and using instruments that measured surface moisture; measured viable airborne microbes	Before vs. after remediation: Reduction in fatigue [OR=0.4 (0.2, 0.7)] Reduction in headaches [OR=0.2 (0.1, 0.7)] Increase in allergic rhinitis [OR=1.5 (1.0, 2.1)]

Reference	Date	Study Type	Sample Size/ Population	Exposure Assessment	Health Effects
Patovirta, et al. (6)	2004	Cohort study	44 teachers from one school with three buildings	Inspected visually and using instruments that measured surface moisture; measured viable airborne microbes	Teachers in moldy vs. non-damaged buildings: Asthma and wheezing 26% vs. 0% prevalence Mean number of sinusitis episodes greater (3.25 episodes vs. 1.25 per teacher , p=0.04) Mean duration of sick leaves greater (22.43 days vs. 2.25 days, p=0.015)
Rudblad, et al. (11)	2001	Cross-sectional study	46 teachers from 2 schools	Target school-reported moisture damage and had building inspected. Control school did not report moisture damage. Participants were surveyed regarding perceived indoor air quality.	Teachers in moisture damaged versus controlled building: Higher levels of mucosal swelling in response to increasing histamine levels (nasal challenge test) More nasal blockage after challenge (p=0.06)

Reference	Date	Study Type	Sample Size/ Population	Exposure Assessment	Health Effects
					Higher prevalence of : Mucous membrane irritation (27% vs. 15%) Allergies (26% vs. 21%)
Thorn, et al. (99)	1996	Case report and cross-sectional study	Index patient (teacher) and 39 coworkers	Investigated building for leaks and measured water content in the walls and floors; performed passive mold sampling in index patient's classroom	Prevalence: Allergic alveolitis (n=1)** Fatigue (>30%)

*Had symptom ≥once per week in past 4 weeks with symptom getting better when away from work.
**Several types of mold antibodies identified in serum of index case.

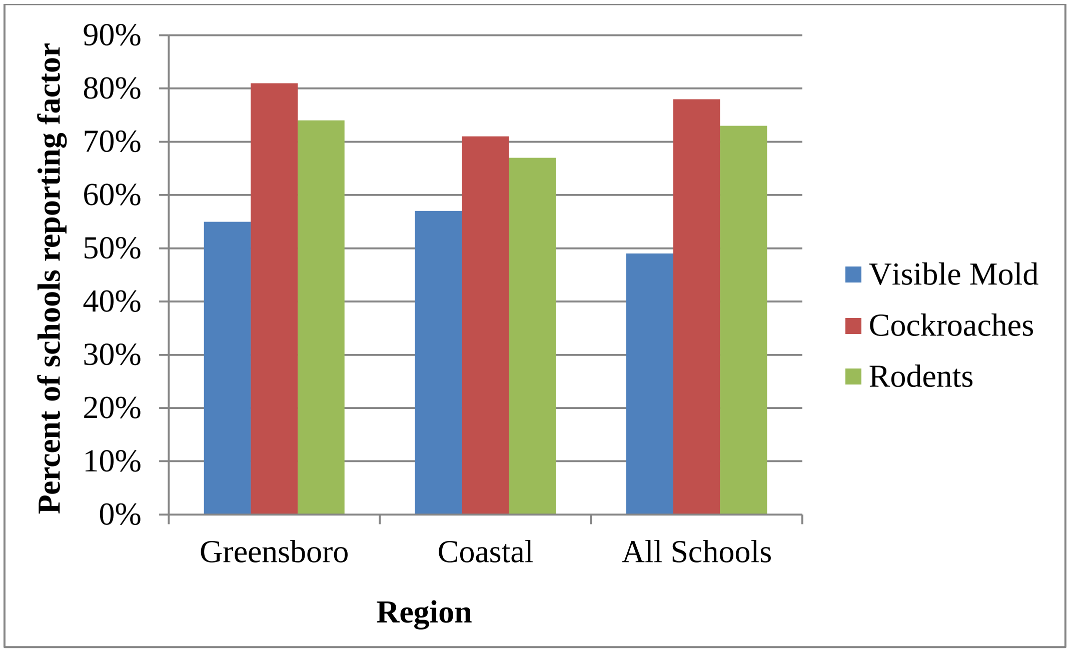
1.9. PRELIMINARY STUDY: 2004 ENVIRONMENTAL HEALTH SURVEY

The Environmental Health Survey, an anonymous questionnaire about indoor and outdoor school environments, was administered to employees of the 337 schools that responded to the NC School Asthma Survey in 1999-2000. During the 2003-2004 school year, over 800 employees from 265 public, middle schools responded to the survey (108-110). Publications that arose from the “Environmental Health Survey: Healthy Schools in North Carolina” study focused on the health effects of proximity of schools to paper mills and hog confined animal feeding operations in eastern NC (108, 110). In addition, employees at 241 schools reported the presence of cockroaches, rodents, mold, and/or a history of flooding in their schools (110).

To better understand the prevalence of these IAQ issues in NC public schools, the researcher acquired these survey data and study reports from the principal investigator, Dr. Maria Mirabelli (111). Use of these secondary data was approved by the University of North Carolina Institutional Review Board [IRB Study# 09-2069].

Unpublished survey data revealed that 35% of schools reported flooding in the past 5 years, 49% reported visible mold inside the school buildings, 77.5% reported ever seeing roaches, 73% reported ever seeing evidence of rodents, and 73% had at least one employee who reported ever smelling mold or mildew. Data from individual schools were grouped by Area Health Education Center (AHEC) regions. At this time, Chapel Hill-Carrboro City Schools were included in the Greensboro AHEC region, and New Hanover County Schools were in the Coastal AHEC region. The Greensboro AHEC region had a higher prevalence of cockroach sightings compared to all schools surveyed, and both regions reported more visible mold than the group as a whole (Figure 1.2). In an open response question, several respondents also indicated concern about asthma or other respiratory issues. These data suggest a high prevalence of moisture-related IAQ problems and confirm the need for further research on asthma triggers in NC schools.

FIGURE 1.1: ASTHMA TRIGGERS BY AREA HEALTH EDUCATION CENTER (AHEC) REGION



2. SPECIFIC AIMS

2.1. INTRODUCTION

Little is known about how classroom RH affects teachers' health or how indoor RH levels may be controlled in a humid climate such as exist in North Carolina. I conducted a longitudinal study collecting data on school indoor air quality factors, classroom RH, and teachers' respiratory symptoms. These data were used to address the following specific aims:

2.2. AIM 1A.

Assess what proportion of classroom-days in each school had mean daily RH within the range (30-50%) recommended for controlling asthma triggers.

2.2.1. Hypothesis

Most (>50%) of the classroom-days in each school will have mean daily RH within the recommended RH range.

2.2.2. Rationale

Examining the ability of schools to maintain daily RH levels within the recommended range will allow us to quantify the extent of the problem of dampness in NC schools. Since all of the schools in our study had mechanical ventilation, we expected that they had some control over the RH levels in the classroom.

2.3. AIM 1B.

Examine associations between classroom RH control and building age, ventilation and maintenance practices, and/or previous water damage.

2.3.1. Hypothesis

Classrooms in newer buildings, schools with adequate ventilation and maintenance and no previous water damage will have RH levels within the recommended range more often than older schools with previous water damage and poor ventilation and maintenance.

2.3.2. Rationale

Identifying factors that improve or hinder classroom RH control will enable us to create targeted recommendations for schools in North Carolina with varying built environments and may inform future school maintenance policies.

2.4. AIM 2.

Evaluate the longitudinal association between average daily RH in each classroom and risk of asthma and cold/ allergy symptoms among teachers, comparing classrooms with high (>50%) and low (<30%) RH to classrooms with recommended (30-50%) RH levels (ref.).

2.4.1. Hypothesis

Teachers in classrooms that maintain daily RH levels within the recommended range will have a lower risk of asthma and cold/ allergy symptoms than teachers in classrooms with RH levels higher or lower than the recommended range.

2.4.2. Rationale

Using quantitative methods to measure dampness over time and surveys to document respiratory symptoms, we will be able to better understand the association between respiratory health and dampness in the work environment. Measuring RH over time is much less resource intense than sampling directly for asthma triggers- mold, dust mites, and cockroach and rodent allergens, which require repeating expensive specialized tests and seeking out expert interpretation. RH monitoring may be a cost-effective strategy to alert schools to potential moisture problems, which can be remediated before causing extensive damage and health effects.

3. MATERIALS AND METHODS: DATA COLLECTION

3.1. OVERVIEW OF STUDY DESIGN

The “Free to Breathe, Free to Teach” study utilized a combination of cross-sectional and longitudinal measurements to examine the relationship between school indoor air quality (IAQ) factors and teachers’ health. Participants provided a baseline self-reported medical history, work history, and home environment risk factor assessment. Repeated surveys called “Weekly Health Diaries” were administered for up to 12 weeks to assess longitudinal changes in health outcomes. These diaries were paired with repeated RH measurements to examine the effect of these classroom environmental factors on teachers’ respiratory health.

School community liaisons advised the researcher that random selection of schools and participants would lead to poor participation due to the already overwhelming burden of paperwork and research on teachers. Therefore, all eligible districts, schools, and participants were invited to participate instead of randomly selecting participants. A detailed comparison of the source population to the study population is outlined in Chapter 6.

3.2. OVERVIEW OF DATA COLLECTION PROCEDURES

Data were collected in 10 schools from 2 school districts, using non-random sampling methods. In these schools, the researcher measured: (1) baseline self- reported medical history of teachers; (2) baseline building and classroom air quality factors; (3) longitudinal RH and temperature; and (4) longitudinal asthma and cold/allergy symptoms among all teachers.

Participant recruitment and data collection were conducted in two phases. Phase 1 included a preliminary test of hygrometers in a year-round New Hanover County school. Phase 2 included a second round of data collection in the remaining schools, using procedures improved by recommendations from Phase 1 participants. Additionally, secondary data were gathered from public sources such as the Department of Public Instruction and the State Climate Office of NC.

3.2.1. Recruitment

School and district recruitment procedures were the same for both phases of the study. Participant recruitment procedures differed slightly between the two phases.

3.2.1.1. Selection of Districts

Administrators from 20 school districts were contacted by the researcher in January 2010, based on referrals from industrial hygienists and previous interest in the Environmental Protection Agency's (EPA) educational program "IAQ Tools for Schools." Superintendents from three school districts provided letters of support for the inclusion of their districts in this study. Due to time and budget constraints, we required commitments from at least 3 schools in each district for that district to remain in the study. One district was not able to meet this requirement and was dropped from the study. A contact person from each district maintenance office was designated as our district liaison. The liaisons provided valuable insight during the design and implementation of the study.

3.2.1.2. Recruitment of Schools

To develop administrative commitment and promote community ownership of the research, the district liaison chose which schools were contacted for inclusion in the study. The researcher gave each liaison a recruitment letter and letter of consent to send via email to principals of potential schools, before each study phase. Because the researcher hoped to capture diversity in school grade levels and resources, liaisons were encouraged to recruit some schools from each grade level (primary, middle, and high school). Thus the school sampling design was non-probability based, heterogeneity sampling (112). Liaisons typically recruited principals who were historically receptive to novel programs and research or those whose schools had previous IAQ issues.

Principals with questions or concerns about school participation were referred to the researcher. After explaining the study purpose and procedures, the researcher or district liaison requested permission from the principals for their school's participation in the study. For their school to officially become a study site, interested principals were required to mail or fax their signed letters of commitment by a stated deadline. The researcher sent out reminders to all recruited principals a few days prior to this deadline.

Once their schools were enrolled, each principal assigned a school liaison. The researcher then scheduled an initial face-to-face meeting with each principal and/or liaison to review the study procedures, answer further questions, acquire a school map, schedule the enrollment training, and meet other essential school personnel such as the custodial supervisor. During these meetings, the researcher also reviewed the school liaison responsibilities, which included logistical planning of site visits and distribution of recruitment and other study materials to school employees, as necessary. School liaisons also granted our study staff access to classrooms and any necessary equipment for study trainings. In most cases, the liaisons fielded questions between the researcher and members of the school community and were enthusiastic promoters of our research and trainings. Later, they provided valuable feedback and insight into their school communities' perceptions of our study.

3.2.1.3. Recruitment and Enrollment of Participants

The researcher recruited participants by convenience sampling from participating schools, with the goal of enrolling as many participants as possible (112). The researcher asked principals to send out an IRB-approved recruitment letter and consent form to all full-time teachers. Recruitment letters included a brief description of the study purpose, outline of participation requirements, and an invitation to the enrollment training. Consent forms contained detailed information about the risks, benefits, and incentives of participating and about the study procedures including privacy policies, participant and investigator responsibilities. The researcher requested that recruitment materials be sent several days before the enrollment training, so that teachers would have time to review them and ask the researcher questions.

During Phase 1, enrollment trainings were scheduled at the convenience of the principals. Half were scheduled during staff meetings and half were scheduled as stand-alone trainings. Originally, Phase 1enrollment trainings were designed to last 30 minutes to an hour, with time to fill out online enrollment surveys built into the agenda. However, only two trainings were able to be held in computer labs. After the other enrollment trainings, consenting attendees were sent a welcome email with the enrollment survey link and instructions within 24 hours.

Since trainings scheduled during staff meetings had better attendance and were more efficient at recruiting participants, Phase 2 school enrollment trainings were scheduled for the next available staff meeting. Enrollment trainings were shortened to 15 minutes, to accommodate the tight schedules of school staff meetings. All phase 2 study participants were sent a welcome email with the enrollment survey link and instructions within 24 hours of the staff meeting.

Enrollment was staggered by school based on the available training date. Some schools had multiple enrollment dates because interested teachers had scheduling conflicts with the enrollment training (i.e. illness, tutoring, or other responsibilities). The researcher did her best to accommodate and enroll all interested teachers by setting up individual or group meeting times with those who notified the researcher of the conflicts.

All enrollment training presentations included a brief description of the study purpose and procedures and explanation of risks, benefits, and incentives. During Phase 1, the incentive was described as a "non-monetary gift of your choice," since we allowed Phase 1 participants to vote on their incentives. During Phase 2 enrollment training presentations, the researcher showed attendees the incentive gift, chosen by Phase 1 participants, and a hygrometer, to familiarize them with the study procedures. Teachers responded positively to these visual tools.

Time was given during the training for questions and after the training for filling out consent and contact information forms. Participants were given blank, electronic copies of the consent forms during Phase 1, with the option of receiving signed, paper copies upon request. All Phase 2 participants received signed, paper copies of their consent forms.

All participants were assigned unique study identifiers (ID) on their pre-labeled contact information forms. If a form was not returned, the researcher retired this study ID to avoid any potential duplicates if the teacher later decided to participate. The researcher paired study IDs with participant names, contact information, and hygrometer ID numbers in an encrypted, password-protected Excel spreadsheet to create the study roster.

After returning their consent and contact information forms, Phase 1 participants received an enrollment packet with their participant identification (ID) numbers, the enrollment survey website, and paper copies of the Weekly Health Diary, one for each week of attempted follow-up, with pre-labeled IDs. Phase 2 enrollment packets contained a copy of the consent form, an instruction sheet with participant IDs, and the enrollment survey link and password.

3.3. ENVIRONMENTAL DATA COLLECTION TOOLS AND INSTRUMENTS

3.3.1. Indoor Air Quality Walkthrough Inspections

As soon as possible after the enrollment training date, the researcher conducted a building inspection at each school with the school's IAQ team to locate the sources of any problems. These inspections focused on classrooms of participants, common areas in the school such as the cafeteria and faculty lounge, and any other areas with suspected IAQ issues. Inspection procedures were based on the EPA's "IAQ Tools for Schools" IAQ Walkthrough Inspection methods, as outlined in the Tools for Schools manual (51).

Two study team members (including the researcher) typically led the IAQ inspection. Phase 1 inspections were led by the researcher and an experienced industrial hygienist, hired to train the researcher in school inspection procedures. Phase 2 inspections were led by the researcher and one research assistant who were typically assisted by the maintenance liaison.

The school's IAQ team consisted of the school's lead custodian and any other school personnel (school nurses, teacher assistants, or other maintenance and custodial personnel) who wished to accompany the study team members. Prior to the inspection, school personnel were invited to attend Tools for Schools IAQ training, which included instructions on forming an IAQ team and examples of a walkthrough inspection. The lead custodian, maintenance personnel, and school administrators were highly encouraged to attend this training and to nominate an IAQ team leader for their schools. The IAQ team leader received a Tools for Schools IAQ Toolkit and other asthma and IAQ resources to share with the rest of the school employees. Participants were not permitted to accompany us on the IAQ inspections, since their rooms were the main objects of the inspection; however, they were permitted to attend the training.

Sensory data (i.e. sights, smells, noises) from the IAQ inspections were recorded by the researcher on forms based on the Tools for Schools IAQ Walkthrough Inspection Checklist. Temperature, relative humidity, carbon monoxide (CO), and carbon dioxide (CO_2) were measured during each classroom inspection using an IAQ air monitor, operated by the second study team member. The Fluke Air Meter 975 (Fluke Corporation, Everett, WA) was used to monitor IAQ factors at Phase 1 New Hanover County Schools (NHCS) and at the Phase 2 NHCS high school, and the KD Airboxx (KD Engineering, Blaine, WA) was used for all other Phase 2 NHCS and all Chapel Hill-Carrboro Schools. Data from the Air Meter were recorded on the Walkthrough Inspection Checklist and entered into a spreadsheet. Data from the Airboxx were downloaded directly into an Excel spreadsheet.

To assess structural risk factors, the researcher asked school staff about district and school level maintenance policies such as HVAC system inspection schedules and integrated pest management (IPM) policies. Building age, HVAC type, flooding history, presence of mold or water damage, types of cleaning supplies, and square footage per full-time custodian were also recorded. In addition, the researcher noted any factors that could have decreased the IAQ such as signs of roaches or rodents, musty smells, and presence of upholstery or carpeting.

When possible, minor issues such as loose air filters were fixed by the lead custodian during the walkthrough inspection. The researcher notified the principal and/or maintenance supervisor's attention of any serious IAQ issues immediately. When necessary, we facilitated collaboration between school staff and local or regional experts to help them develop cost-effective remediation plans for more complex problems.

3.3.2. Heating, Ventilation, and Air Conditioning (HVAC) Survey

After consulting with two industrial hygienists on important HVAC factors to include in the Aim 1 analysis, it became apparent that not all of the essential variables had been collected. Therefore, in May 2013, the researcher administered phone surveys to district maintenance liaisons about the HVAC systems of all schools participating in "Free to Breathe, Free to Teach." The HVAC surveys collected information about cooling mechanism type, HVAC controls, thermostat setbacks, presence of economizers, and systemic dehumidification processes.

If a building's system had been renovated since data collection in 2011, the liaison was asked to answer the questions referring back to the system that was in place at the time of data collection. Results were recorded by school building, except in the case of 10 classrooms with different HVAC systems than the rest of the building.

3.4. HYGROMETERS

3.4.1. Testing Overview

Extech Data Loggers Model 42270 (Extech Instruments Corporation, Nashua, NH) were used to measure temperature and RH longitudinally for this study. The study team performed several tests on the instruments to evaluate their performance within the school environment, since their suggested usage was for storage facilities. Another goal of the hygrometer testing was to measure the variability within the school environment to estimate how many instruments were necessary to attain the best balance of cost and data quality.

3.4.2. Instrument Functionality

To ensure that all hygrometers were functional, the researcher placed them in a small indoor area (7"X14") and programmed them to record every 30 minutes, simultaneously. During the recording period, the researcher varied the temperature and humidity by manipulating the thermostat, turning on the shower, and opening or closing the windows. All hygrometers recorded the correct date and time, temperature corresponded closely to the thermostat readings, and the humidity reflected environmental manipulations to increase or reduce humidity.

3.4.3. Between Instrument Variation

To examine whether the between-instrument measurement variation was dependent on ambient temperature and humidity, the hygrometers were run in a climate controlled room and an uncontrolled outdoor sheltered structure, with 33 data loggers simultaneously recording temperature and humidity every 15 minutes. During the outdoor test, ambient temperature and humidity were varied naturally throughout the course of the day. During the indoor test, temperature and humidity were varied by alternately cycling the air conditioning unit and later turning on a shower for 15 minutes. Outdoor relative humidity range during these tests was 56.4-82.3%, and indoor RH range was 44.8-71.9%. The outdoor temperature range during these tests was 78.1-87.4^{o}F (25.6-30.8^{o}C), and indoor temperature range was 72.7-82.0^{o}F (22.6-27.8^{o}C). The standard deviations of all except five average indoor RH readings and ten outdoor average RH readings were less than 1. Excluding these outliers, there was a linear relationship between outdoor and indoor average RH and their standard deviations (Figures 3.1 and 3.2). The standard deviations of all except nine average indoor temperature readings and four outdoor temperature readings were less than 0.3. A positive, linear relationship existed between the standard deviations and average outdoor but not indoor temperature, which showed no apparent linear relationship with standard deviation.

The between instrument variation for all temperature and RH readings seemed to be greatest for the first three readings, suggesting that there is some minimal warm-up period needed for the instruments. For all parameters except outdoor temperature, outliers were found within the first 10 observations.

FIGURE 3.1 SUMMARY OF INDOOR RELATIVE HUMIDITY (%) READINGS (N=33 HYGROMETERS)

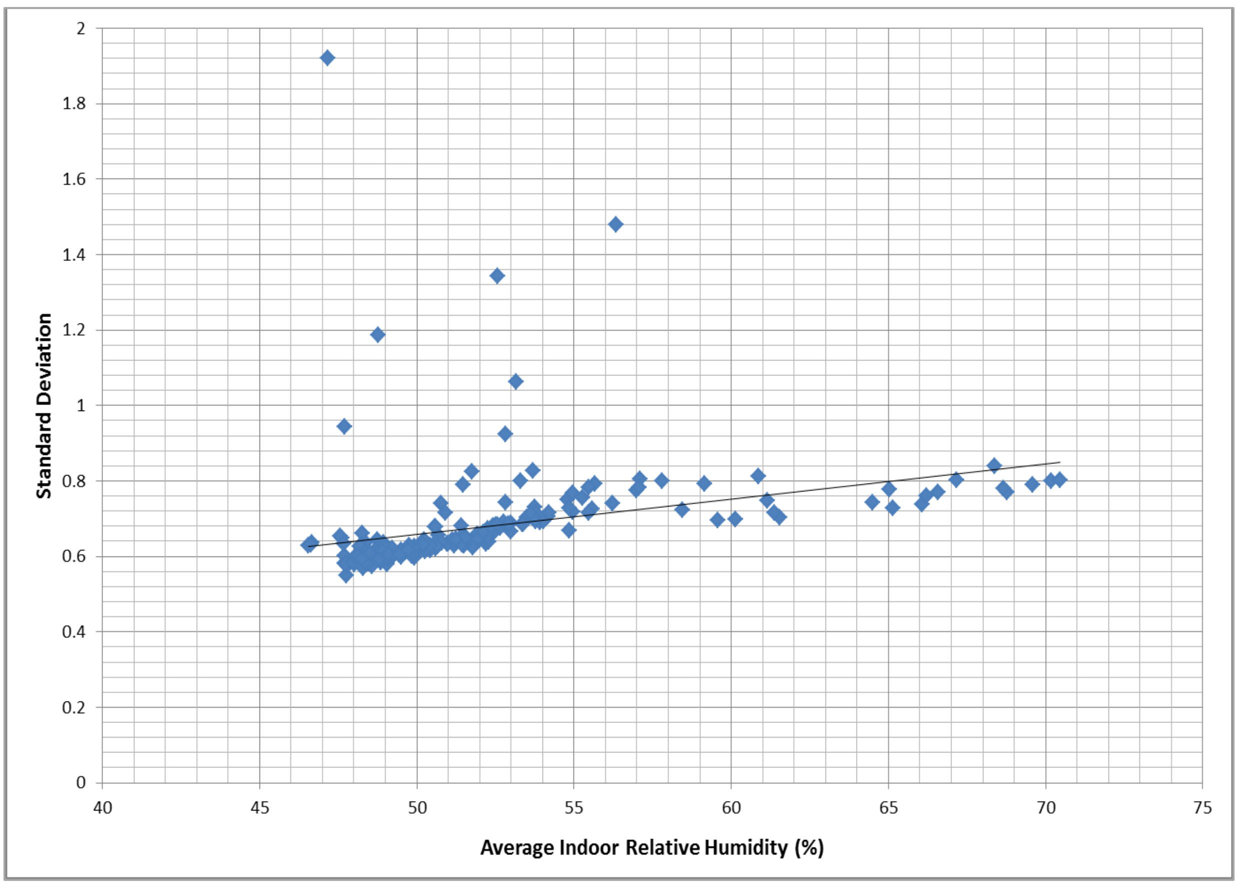
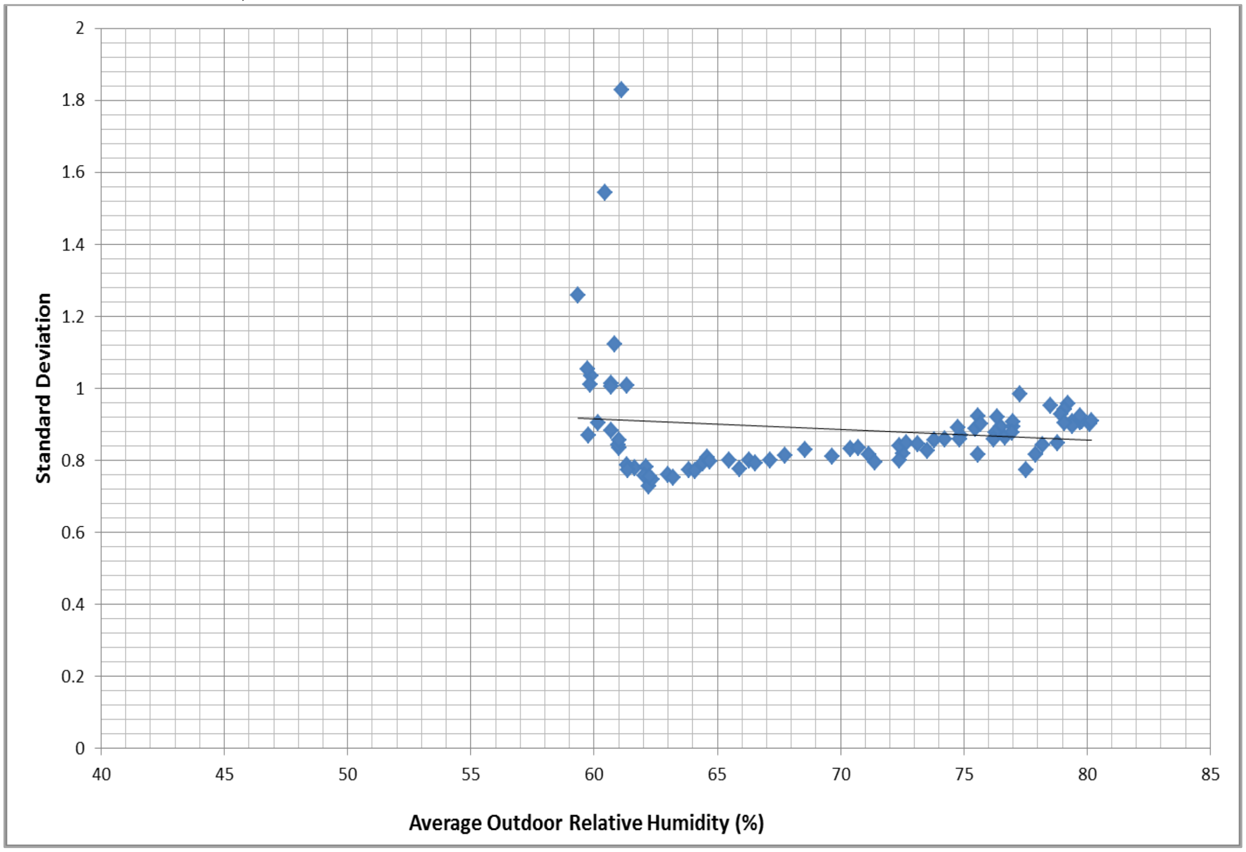


FIGURE 3.2 SUMMARY OF OUTDOOR RELATIVE HUMIDITY (%) READINGS (N=33 HYGROMETERS)



3.4.4. Between and Within Classroom Variance Test

To test the between classroom variance in hygrometer readings, the researcher placed hygrometers in 26 elementary school classrooms, simultaneously recording every 15 minutes during a school week in August. To estimate the within classroom variance in hygrometer readings, 3 hygrometers were placed in separate corners of the media center and a science classroom. In the science classroom, an additional hygrometer was placed in next to one of the 3 hygrometers to capture differences in measurements between instruments. For "gold standard" comparison, a temperature and RH reading was taken in each location at the start of each hygrometer's recording period using a sling psychrometer. Hygrometer data were imported into SAS, averaged for each day, and analyzed using graphical methods visually comparing classroom averages. Classroom temperature and RH averages tended to stay in rank order over time. Hygrometer data for most classrooms had peaked, non-normal distributions. Analysis of variance (ANOVA) and mixed models were used to compare variances in weekly average temperature and humidity by classroom and within quadrants of the school building. RH did not vary much within one room or within one week for one classroom; however, it did vary substantially between classrooms. These findings were consistent with a study in unoccupied test homes that showed little variation in temperature within one room (49). Therefore, the researcher modified the study design to focus on health effects of being in a classroom with extreme average RH levels on a given day. Due to the small number of participants, we had enough hygrometers to monitor each classroom for the whole follow-up period.

3.4.5. Instrument Accuracy

To test the accuracy of the hygrometer measurements, the researcher conducted a series of four hygrometer calibration tests in which all hygrometers simultaneously recorded humidity and temperature in the same location. Hygrometer readings were compared against humidity and temperature measurements taken using the sling psychrometer. The differences between the hygrometer and psychrometer readings were small and possibly due differences in units of measurement between the hygrometer and psychrometer.

Sling psychrometer procedures included wetting the wick of the wet bulb using distilled water, blotting the wick with a felt cloth, and spinning the psychrometer for 30 seconds before reading the alcohol-based thermometers. Wet and dry bulb temperatures were measured to the nearest 0.1^{o}C and converted into RH based on the barometric pressure in Chapel Hill, NC at the time of the readings, using an online calculator provided by the National Oceanic and Atmospheric Administration (NOAA) (113). Average barometric pressure (inHg) on test days was extracted from the NC Climate Retrieval and Observations Network of the Southeast (CRONOS) database, Chapel Hill-Williams Airport station (114).

Calibration test data were imported into SAS from text (hygrometer) and Excel files (sling psychrometer). Digital hygrometer data were plotted in SAS against the sling psychrometer data. A research assistant estimated the slope and intercept for the linear relationship between the hygrometer and psychrometer data in SAS, to determine the deviation of the hygrometer measurements from the sling psychrometer readings. The slopes and intercepts became the calibration factors for analysis. The researcher "corrected" the hygrometer data from the environmental study measurements using a standard linear equation for each hygrometer, applying the calibration factors and outputting the calibrated data points to a new dataset. The range for the calibrated RH was -9 to 200%, which was outside of the range of possible RH values (0-100%). The calibrated temperature data were also outside of the possible range.

After rechecking the estimation methods for the calibration factors several times and finding no errors, the researcher decided not to use these as correction factors. Though tests were performed during the heating (January 2011), cooling (September and July 2011), and transitional air conditioning periods (October 2010) to capture a range of indoor environmental conditions, the calibration regression lines were poorly fit (R squared <0.80). Much of the data were extrapolated since the ranges of measurements taken in the classrooms were much broader than the ranges of measurements taken in the test areas. Because of the poor calibration data fit and since the company stated that all data loggers were factory calibrated [±0.6^{o}C accuracy for normal (-20 to 50 ^{o}C) temperature conditions and ±3% accuracy for RH], I did not use the calibration factors in my analyses.

3.4.6. Longitudinal Hygrometer Data Recording

At the start of follow-up, one data logging hygrometer was placed in a participant's breathing zone at the participant's desk or near the podium or board in the main classroom, wherever the participant spent most of his or her time. When possible, additional hygrometers were assigned to participants who indicated that they spent more than a half hour each day in another location (i.e. cafeteria or faculty lounge).

Using the Extech data logging software and hygrometer docking station, hygrometers were programmed to record RH (%) and temperature (^{o}F) every 15 minutes for the duration of the follow-up period. To coincide with the beginning of the WHD follow-up, all hygrometers were set to start recording at 12pm on Sunday of Week 1 of follow-up. A study team member transferred data from each hygrometer to the study laptop weekly and visually checked the data to verify that the instruments were recording properly. After the data transfer was complete, the team member returned the hygrometer to the assigned location, as noted on a spreadsheet.

3.5. HEALTH AND DEMOGRAPHIC SURVEY INSTRUMENTS

3.5.1. Questionnaire Development and Choice

3.5.1.1. Enrollment Survey

The enrollment survey consisted of baseline questions on work history and demographics, as well as questions from the 2008 Behavioral Risk Factor and Surveillance System (BRFSS) "Asthma Call-back Questionnaire for Adults" which assessed home exposures and self-reported chronic respiratory diagnoses including asthma (115). Work history questions were created by the researcher. Demographic categories for income, ethnicity, education, and race closely matched those used for the 2009 American Community Survey (116). Participants entered their unique study ID rather than names into the Qualtrics survey, so survey data were anonymous. However, the researcher put demographic questions at the end of the enrollment survey, since they were the most sensitive questions on the survey and might deter participants from completing the other questions if placed in the beginning of the survey.

3.5.1.2. Weekly Health Diary (WHD)

During follow-up, participants recorded respiratory, skin, cold/flu/allergy, stomach, and general "sick-building" symptoms (fatigue, headache, and dry cough) in "Weekly Health Diaries." Though stomach symptoms were unrelated to the hypotheses, the researcher added these symptoms to allow for later analysis of potential reporting bias. The diaries also asked about allergy medication usage, absences due to illness, hours worked each week, and time-varying environmental factors such as carpool duty or dehumidifier use. The researcher created all questions for the Weekly Health Diaries (WHD) using the Rural Health Survey as a guide for format and symptoms (117).

To balance optimum symptom recall time with minimal time commitments for the study participants, the researcher asked participants to report their health symptoms weekly. Juniper, et al. found that the concordance between their weekly Asthma Control Questionnaire (ACQ) and daily diaries was high [intraclass correlation coefficient (ICC) =0.87] and that the reliability and evaluative properties of the ACQ were slightly better when compared with the daily diaries (118). Therefore, weekly asthma and allergy symptom recall was likely similar to daily symptom recall in this population as well.

3.5.1.3. Asthma Control Test$_{TM}$ (ACT)

Several validated questionnaires existed which were highly reliable and responsive to changes in adult asthma control over time-- including the Asthma Control Test$_{TM}$ (ACT), Asthma Control Questionnaire (ACQ), Asthma Quality of Life Questionnaire (AQLQ), Perceived Control of Asthma Questionnaire (PCAQ), and Asthma Therapy Assessment Questionnaire (ATAQ) (119-127).

The ACQ was originally chosen as the survey instrument, since it has a validated and well-studied scale (118, 121, 122, 128). Asthma control has been reliably measured in the ACQ both with and without the FEV1% question (128). However, the survey reviewers had concerns over the ambiguity of the ACQ response categories, as well as the British rather than American English standard usage for the wording of several questions (see section 3.4.1). The researcher was not permitted to change the wording of the ACQ; thus, it was necessary to find another measurement tool.

The PCAQ was tested on a diverse group of participants, more similar to our source population. However, this questionnaire focused mostly on respondent's feelings about his or her asthma, rather than symptoms or perception of control for the week (123). The AQLQ was created to measure change in physical and emotional health of asthmatics with a two week recall period. However, it contains 32 questions which would be prohibitively time consuming for teacher participants (125). Therefore, the AQLQ and PCAQ were not appropriate for this study.

The ACT and ATAQ measure asthma control over 4 weeks, with no approved version for acute (weekly or daily) recall of symptoms, since both were created for clinical use (119, 124). The ACT was chosen because it had been widely used and tested among American patients. In addition, a study testing the validity of the ACT to assess asthma control among American adults found that 41% scored below 19, indicating that they did not have well controlled asthma, although only 15% of them rated their asthma as "poor/ not controlled" (76). Therefore, the ACT seemed to be a more sensitive measure than self-reported asthma control. Since the ACT also only consists of five questions, the researcher chose it as the best-fitting survey for our study population's time constraints.

The time and expense involved in being able to measure airway restriction for our study outweighed the benefits to having a clinical measure. Due to our limited resources, this study did not have any clinical measure of airway restriction. However, the ACT has a fairly high sensitivity [controlled= 0.77 (0.68-0.84); not well controlled= 0.75 (0.63-0.83); uncontrolled= 0.49 (0.42-0.56)] and specificity [controlled= 0.84 (0.74-0.91); not well controlled= 0.82 (0.76-0.87); uncontrolled= 0.92 (0.86-0.96)] for all categories except uncontrolled asthma (129).

However, the researcher was concerned about capturing asthma symptoms in undiagnosed teachers and weekly symptom variations in asthmatic teachers. To address this concern, questions about asthma symptoms were also included in the WHD for all participants.

3.5.2. Survey Instrument Testing Procedures

3.5.2.1. Phase 1 Survey Testing

Six reviewers evaluated the consent form, Asthma Control Questionnaire (ACQ), enrollment survey, and weekly health diaries for ease of completion, formatting, and clarity of content. Reviewers were selected for their expertise in education or surveys.

Reviewers were given paper or electronic copies of all study instruments which they commented on and returned within a month. Suggestions included revisions of content, layout, formatting, and grammar. Based on advice from the reviewers, all Phase 1surveys were administered on paper except for the enrollment survey, which was web-based for faster completion of study enrollment. After each stage of revision, study instruments were submitted to the UNC IRB for approval before use with participants.

Several reviewers had concerns regarding the ACQ response categories and the use of British rather than American Standard English, thus, the Asthma Control Test$_{TM}$ (ACT) was chosen instead to measure asthma severity and control (127). See section 3.5.1.3 for a discussion of asthma survey instrument choice.

3.5.2.2. Phase 2 Survey Modification

After Phase 1 data collection was completed, a Participant Feedback Survey was created to record participants' impressions of the study and any recommendations that they had for improvement of future participants' experiences. Phase 1 participants who consented to be contacted for feedback were called in January 2011 by an epidemiology student volunteer, who recorded their responses in Qualtrics (130). Participants who could not be reached by phone after two attempts were emailed the survey link.

Phase 1 participant feedback about the WHD suggested that they found the paper surveys difficult to manage and preferred online surveys. Disagreement between reviewers and participants may have been due to two of the reviewers being retired and thus not aware of current teachers' constant use of and increased comfort level with the internet. Therefore, WHD were administered via Qualtrics web-based surveys during Phase 2 (130).

Switching to online surveys had many benefits. The time-intensive data entry of paper surveys was eliminated as well as many potential data entry errors. In the web-based survey, Phase 2 participants were responsible for entering their study ID numbers; however, survey links were unique to each participant so that errors in ID entry could be corrected. The researcher encouraged participants to contact her if they forgot their IDs.

During Phase 1 reminder emails, the researcher gave the participants the survey week number for perspective on the length of data collection, but participants occasionally wrote the wrong week number on their surveys. Such errors were correctable if participants filled out surveys on time and if the week number could be logically deduced. However, misclassification of symptom date may have occurred when surveys were late and/or missing week number.

In addition, participants had different interpretations of “Survey Date” and answered with the date of survey completion (the intended answer), the last date of the survey week, or range of dates covering the reference survey week. These different interpretations led to confusion over when symptoms actually occurred. The use of Qualtrics survey software in Phase 2 had the additional benefit of tracking response dates, thus removing the ambiguity of the variable “Survey Date” (130). The researcher also listed reference dates and days of the week above each symptom grid in each Phase 2 WHD, for further clarity.

Phase 1 survey weeks went from Saturday to Friday so that participants could fill out the survey at the end of the work week. Having the week start on Saturday added more confusion for some participants, and only 51% of the surveys were filled out on Friday. Therefore, in Phase 2, the survey week began on Sunday and ended on Saturday, to match the calendar week.

During Phase 1, the survey asked questions related to the amount of time spent in the classroom each day. These questions were simplified for Phase 2 due to confusion over the answer choices in Phase 1. Also, instructions for all time-related questions were reviewed in detail during the Phase 2 enrollment training to improve data quality.

Online, direct data entry allowed the researcher to track survey completion in real-time and send reminders only as necessary. The reminder process was further simplified using school-specific, participant lists so that this task could be assigned to research assistants.

The format of Phase 2 WHD was also slightly different, with the wording and structure of some questions changed to better fit the online administration. Skip patterns were programmed with quick “yes/no” screening questions for each symptom type, which reduced the number of survey questions that participant viewed on each page and overall. Whereas, all Phase 1 WHD contained some asthma-related questions which participants had to complete or skip depending on their asthma statuses; a separate survey was created for Phase 2 asthmatic teachers so that they would be the only ones asked questions about asthma control and severity. Conversely, non-asthmatic participants were asked weekly whether they received an asthma diagnosis during the follow-up period. These modifications shortened the survey for all participants.

Questions were added to Phase 2 WHD to gather information on additional time-varying exposures including cafeteria duty, the presence and type of air fresheners in the classroom, new medication use, and days when allergy medications were taken. The Phase 2 survey for asthmatic teachers also asked questions about rescue and controller medication use, not previously included in the Phase 1 questionnaire.

3.5.3. Baseline Enrollment Data Collection Procedures

Contact information forms requested the participant’s name, school name, classroom name/ number, email address, phone numbers, and preferred mode of contact. Birthdates were also collected on this form, so that all identifiers could be stored separately from health data and later shredded to further protect participants’ identities. The investigator and research assistants also recorded hygrometer ID numbers on these forms during hygrometer placement.

Within 24 hours after consenting to participate in the “Free to Breathe, Free to Teach” study, consenting teachers were sent a welcome email with the enrollment survey web link, instructions, deadline, and password reminder. The participants were officially enrolled in the study after completing the enrollment survey. Enrollment trainings were typically held on Wednesdays, welcome emails were sent on Thursdays, and enrollment survey reminder emails were sent on Monday of the following week. Individual participants who did not complete the enrollment survey by the deadline continued to receive weekly enrollment reminders until it was completed or until the participant notified the researcher of his or her withdrawal from the study.

During Phase 1, teachers' schedules were requested during the online enrollment survey, including any rooms that participants occupied for more than 30 minutes per day. However, having this question on the enrollment survey delayed hygrometer placement until participants completed these surveys. To improve our hygrometer placement during Phase 2, the researcher asked enrollees to list their schedules on the back of the contact information forms.

3.5.4. Follow-up of Participants

Follow-up length (t=4 to12 weeks) depended on the date of school enrollment. For both phases, follow-up began on the Monday following the enrollment training.

3.5.4.1. Weekly Health Diaries (WHD)

Paper copies of the Weekly Health Diaries (WHD) were given out in manila envelopes during Phase 1 enrollment trainings. Each copy was pre-labeled with the participant's study ID. To protect participant anonymity, completed surveys were returned to a locked, drop box labeled with the study logo and placed in the teachers' lounge. The researcher picked up surveys from the drop box each week during site visits, which were also used to remind participants to turn in late surveys. Email reminders were sent to participants before each weekly site visit. Participants who lost their survey packets could email the researcher to receive a replacement packet.

For both phases, participants received reminder emails on every Friday starting on the first week of follow-up (Week 1) instructing them to complete their WHD. Additional email reminders were sent out at the beginning of the following week, as necessary.

Phase 2 WHD were sent electronically through a Qualtrics survey link every Friday (130). If the participant did not complete his or her survey, a reminder email with survey link was sent to that participant on the following Wednesday and every subsequent Wednesday until that week's survey was completed.

3.5.4.2. Asthma Control Test$_{TM}$ (ACT)

Teachers who reported asthma at baseline were asked to complete the monthly Asthma Control Test$_{TM}$ (ACT), which added five extra questions per month to the existing survey completion load (127). Due to restrictions from QualityMetric Incorporated on web-administration of the ACT, this survey was administered on paper via the QualityMetric-approved survey forms for both phases of the study (127). With their permission, spaces for participant ID and survey date were added to the header of the form. Participant ID was pre-labeled by the researcher. Participants were asked to write the date when they completed the survey as the survey date. Questions in the survey referred to the preceding 4 weeks.

During the following site visit after the participants completed their enrollment surveys, asthmatic teachers received an envelope with several copies of the ACT. The researcher sent monthly emails to asthmatic participants when it was time to take the ACT. Due to the shortened length of follow-up, Phase 1 participants completed only one ACT each; whereas Phase 2 participants completed up to three ACT.

During Phase 1, completed WHD and ACT surveys were returned to a locked drop box in the teachers' lounge and collected each week by the investigator. During Phase 2, only the ACT was returned to the drop box, which was checked weekly by either the investigator or research assistant. Surveys collected by the research assistant were mailed or given to the investigator at her next site visit. For added security, return envelopes were provided.

If an ACT was not completed and returned by the stated due date, a reminder email was sent each week until it was returned. Electronic copies of the ACT were attached to each reminder email, in case the participant could not find the paper copies. Participants were asked to print out and return paper copies of the ACT, since the electronic version was not fillable.

3.5.4.3. Study Incentives

Initially, district administrators were interested in participating in the study because of the incentive of “IAQ Tools for Schools” training and inspection. The “IAQ Tools for Schools” Program was created by the EPA to train school employees on how to prevent, detect and solve IAQ issues in schools using readily available technologies and simple, cost-effective solutions (51). District maintenance employees were invited to attend all “IAQ Tools for Schools” introductory trainings held in participating schools. The researcher also coordinated a district-wide “IAQ Tools for Schools” training with EPA regional experts, which was conducted separately in each district during the spring semester. Each district’s training focused on topics requested by the district maintenance liaison. To show our appreciation for their time, the district liaisons received “IAQ Tools for Schools” Toolkits, tote bags, and a travel mug.

School nurses were invited to district-wide “Open Airways for Schools” (OAS) trainings conducted by the American Lung Association (131). Nurses from schools participating in “Free to Breathe, Free to Teach” received free OAS classroom kits.

The benefits to schools participating in the study were enumerated in the principal recruitment letter. Besides making a contribution to the knowledge of respiratory health among NC teachers and IAQ management in NC schools, participating schools received the EPA’s “IAQ Tools for Schools” Toolkit during the introductory training and a hygrometer with docking station at the end of the study. The IAQ coordinators at each school received a bag with asthma education materials and IAQ resources such as “No Idling” signs for their schools. The principal, school liaison, and lead custodian also received a travel mug with the study logo.

The researcher offered optional, introductory, “IAQ Tools for Schools” trainings to all interested school employees and support with implementing the “IAQ Tools for Schools” program. Walkthrough inspection procedures were taught as part of the “IAQ Tools for Schools” training and involved inspecting classrooms and common areas for existing or potential IAQ issues. All participating schools were nominated for “IAQ Tools for Schools” awards for new and/or exemplary IAQ programs.

The investigator solicited ideas from survey reviewers and Phase 1 school contacts on participant incentives. A voluntary participant incentive poll was sent to all Phase 1 participants at the end of follow-up, to give them the opportunity to vote on the study incentive gift. Votes were tied between the stainless steel travel mug and the stainless steel water bottle. Since Phase 1 ended in the winter, the researcher chose the mug as the final incentive. In February, Phase 1 participants who turned in at least half of their surveys received “thank you” cards; travel mugs stamped with the study logo; asthma stickers provided by the NC Asthma Program; and mold prevention educational magnets provided by the EPA’s “IAQ Tools for Schools” program. Participants who completed all of their surveys also received a plastic storage box.

Since Phase 2 follow-up was much longer than Phase 1 follow-up, the researcher provided a $5 gift certificate as an extra incentive to prevent participation fatigue. Research assistants gave out gift certificates to participants as soon as they completed the number of surveys equaling half of the required surveys (i.e. 6 of 12 required surveys), regardless of whether surveys were missing for some weeks. Gift certificates came from local food establishments in which $5 could cover a typical purchase (i.e. Maple View Creamery for Chapel

Hill-Carrboro City Schools and Port City Java for New Hanover County Schools). In addition to the $5 gift certificates, Phase 2 participants who completed all surveys received the same incentive gift as in Phase 1. Phase 2 participants who completed at least 80% of the required surveys received the above incentive gift without the storage box.

3.6. STUDY WEBSITE AND TRAININGS

During Phase 1, a study website (www.unc.edu/~kangelon) was created to host the link to the web-based enrollment survey and provide blank copies of the WHD, ACT, and consent form for teachers to download if they misplaced their study packets (127). The researcher also featured IAQ classroom tips from the "IAQ Tools for Schools" curriculum guide.

All participating schools were offered Open Airways for Schools (OAS), Asthma 101, Healthy Homes, and "IAQ Tools for Schools" Introductory training. All school nurses from each participating school district were invited to an all-day OAS and Asthma 101 training, conducted by the North Carolina American Lung Association (ALA) trainer. OAS is a training of trainers, geared towards educating school health professionals on how to educate middle school students on how to control their asthma and recognize their asthma triggers; however many of the skills can be transferred to students of all ages. Asthma 101 is a brief overview about asthma and how to prevent asthma-related health emergencies, geared towards all school employees. At these trainings, the researcher also presented a study summary and brief overview of the importance of controlling classroom asthma triggers. All asthma training attendees received asthma education materials from the EPA, and all attendees from participating schools received OAS curriculum kits. The ALA training fee and materials were covered by the researcher through a North Carolina Public Health Association scholarship, and Merck sponsored the lunch for the New Hanover County training, so that both trainings were free for participants.

In January, Phase 1 schools were offered “Healthy Homes” training, which demonstrated ways to improve IAQ in homes and classrooms through presentations and hands-on activities which could be used as classroom activities. These trainings were co-instructed by the researcher and the “Healthy Homes” trainer from the UNC Office of the Environment. Due to challenges with scheduling “Healthy Homes” trainings for Phase 2 schools, a webinar was offered instead. The study website hosted the link to the webinar and webinar evaluation.

Before the researcher conducted an IAQ inspection of participating schools, “IAQ Tools for Schools” Introductory training was offered to all school staff members. In this training, the researcher covered the basics of school IAQ and took participants through a “virtual walkthrough inspection” using pictures from an example school. Attendees received IAQ and asthma education materials. Attendance at these trainings varied depending on the school level, scheduling conflicts, and interest of employees.

4. MATERIALS AND METHODS: DATA MANAGEMENT AND CLEANING

4.1. HYGROMETER DATA

4.1.1. Management

The original hygrometer data were downloaded using the Extech data logging software and hygrometer docking station and stored as text files. Each hygrometer file contained one to two weeks of data. After checking the data, the researcher merged all files in SAS to form a database for each phase.

4.1.2. Cleaning

After importing the text files into SAS, the researcher randomly checked 1% of the observations in half of the SAS files against the original hygrometer text files, to ensure that they imported correctly. In addition, Proc Compare was used to compare files imported and merged in SAS versus files imported and merged in Stata.

The researcher checked the distributions of RH and temperature and the number of files per hygrometer ID. Five text files were internally labeled with incorrect hygrometer IDs and were corrected in the SAS file to match the hygrometer number in the filename. This error may have occurred when transferring data if the study team member forgot to change the ID number from one hygrometer to the next when resetting the hygrometer.

The last observation in each hygrometer file was typically an extreme outlier and/ or an observation that overlapped in time with the first observation on the next sequential file. This error occurred when an observation was recorded while the study team members were transferring the data from the data logger. Since the error was created randomly, dependent on whether the hygrometer was in the dock while the last observation was recording, the last observation in each file was systematically dropped.

Ten hygrometers malfunctioned due to the hygrometer falling off of the wall. Participants notified the researcher when the hygrometers fell and they were moved to safer locations at the next site visits. The data logger set observations (n=2423) recorded after the malfunction to the year 2000, thus they were easy to identify. Because the actual dates and times of these observations were uncertain, these observations were deleted.

4.2. INDOOR AIR QUALITY (IAQ) WALKTHROUGH INSPECTION

4.2.1. Management

The researcher modified the EPA's Walkthrough Inspection Report template provided in the "IAQ Tools for Schools" Toolkit to record our findings during our school inspections. Walkthrough inspection data were entered into an Access database by two research assistants, with separate tables for each school. The researcher imported these data into SAS and merged them to form one database for walkthrough inspections.

4.2.2. Cleaning

The researcher performed 100% double entry of all IAQ walkthrough inspection data.

4.3. STUDY ROSTER

4.3.1. Management

Data from participants' contact information forms, including participants' names, contact information, birthdates, and school names and unique school codes (created by the researcher), were entered into an Excel spreadsheet which became the study roster. Information about survey completion, follow-up schedules, hygrometer issues, participant exclusion or censoring, and incentive gifts were also recorded on the study roster.

4.3.2. Cleaning

A random sample (10%) of birthdates and identifiers from the study roster were checked against the original contact information forms for data entry errors. No errors were found.

4.4. ENROLLMENT SURVEY

4.4.1. Management

Enrollment survey data were collected through Qualtrics web-based software (130). At the end of each phase, the researcher downloaded de-identified versions of the enrollment survey data from Qualtrics into Excel spreadsheets, after dropping users' email and Internet Protocol (IP) Addresses (130). The study ID number remained in the database to identify participants. Next the researcher imported the Excel spreadsheets into SAS version 9.2 for analysis and merged the enrollment survey databases from the two phases (111).

4.4.2. Cleaning

Ten percent of the observations in the enrollment databases were checked against the original data in Qualtrics, to ensure that the data were correctly imported into SAS (111, 130). While cleaning the enrollment survey data, the researcher found several outliers among the answers to the question, “What is the average number of hours that you work at school per week?” Ten of these outliers were less than 30 hours per week, which raised a question about the full-time status of the participants. Participants were contacted for clarification, and all replied that they were full-time. Participants may have thought that the question was asking about number of hours worked per day, since 9 out of 10 of these participants answered less than 10 hours. Full-time status was also called into question for one participant who reported an associate’s degree, rather than the bachelor’s degree required for all full-time teachers in North Carolina. This participant was not classified as a “full-time, classroom teacher” by the Department of Public Instruction and so was dropped from the study.

During Phase 1, one participant realized that she had mistakenly put the wrong study ID on her enrollment survey. This mistake was corrected in SAS after the data were imported.

4.5. WEEKLY HEALTH DIARIES

4.5.1. Management

For Phase 1, Weekly Health Diaries (WHD) were self-administered on paper. The researcher entered all Phase 1 WHD data into a single Qualtrics database after follow-up was completed (130).

Phase 2 WHD were self-administered online through Qualtrics, with two separate surveys for each survey week-- one for asthmatic teachers and another for non-asthmatic teachers.(130). Since this was a new format, the initial month of surveys was checked by the researcher and directions were clarified if participants seemed to be confused about question wording.

The numerically coded versions of all WHD databases were downloaded from Qualtrics into Excel spreadsheets in .csv format and then imported into SAS (111, 130). A data programmer merged Phase 2 WHD data in SAS to create one WHD database to be merged with the Phase 1 database. The programmer than merged all WHD data with the ACT data and environmental data to create the Aim 2 analysis dataset, by linking participant IDs with classroom IDs.

4.5.2. Cleaning

A research assistant checked all Phase 1 WHD Qualtrics data against the original paper surveys for accuracy of data entry and survey completion (130). Out of 31 total data errors, 12.9% were due to data entry from paper into the online database. The researcher corrected these errors directly in Qualtrics (130). The remaining 87.1% of data errors were due to survey completion errors including missing survey dates and/or week numbers (n=3), other missing data (n=5), confusing or conflicting survey dates and/or week numbers (n=12), conflicting or confusing answers to other questions (n=5) and filling out duplicate surveys for the same week (n=2). Participants were contacted for clarification if necessary, and all data corrections were documented and standardized according to rules set by the researcher.

Ten percent of the observations in the final WHD databases were checked against the original data in Qualtrics, to ensure that the data were correctly transferred between programs (130). For the Phase 2 WHD asthma surveys with <10 observations in each week's dataset, the first observation of each SAS dataset was checked against the original Qualtrics data (130). For all other datasets with >10 observations, the researcher randomly chose the observations using a random number generator (132). If the last digit of the number of observations ≥ 5, then the researcher rounded up and checked an extra record. For example, if a database had 56 observations, then six numbers were randomly chosen using the random number generator. These six numbers corresponded to the observation numbers assigned in the SAS database and were linked to the online survey entry via the response ID assigned by Qualtrics (130).

Distributions of all variables were checked using frequencies for dichotomous and categorical variables and univariate diagnostics (mean, range, and shape of distributions) for continuous and categorical variables. If any values seemed outside of the expected range, the researcher contacted the participant for clarification.

4.6. ASTHMA CONTROL TEST$_{TM}$ (ACT)

4.6.1. Management

For both phases, the Asthma Control Test$_{TM}$ (ACT) was self-administered on paper (127). The researcher entered the ACT data for each phase into a separate database in the QualityMetric Health Outcomes™ Scoring Software 4.0, which calculated the total ACT scores (QualityMetric Incorporated, Lincoln, RI, 2010). Scored results were then downloaded into Excel spreadsheets and imported into SAS (111).

4.6.2. Cleaning

SAS ACT databases were checked against all paper surveys for quality of data entry and correctness of data import. Distributions of all variables were checked for outliers using frequencies. A data programmer extracted participant IDs from ACT IDs and used the participant IDs and calendar week numbers to merge the ACTs with WHD data.

4.7. HEATING, VENTILATION, AND AIR CONDITIONING (HVAC) SURVEY

4.7.1. Management

HVAC survey data were entered directly into Qualtrics by the researcher while administering the survey to the maintenance liaisons. HVAC data were downloaded into Excel spreadsheets and imported into SAS, where they were merged into one dataset.

4.7.2. Cleaning

HVAC data collection was standardized between the two school districts. Since datasets were small, the researcher visually compared all data for accuracy after importing into SAS. The researcher checked distributions of variables using frequencies. Variable categories with a small sample size (n<5) were merged with similar categories, where appropriate.

4.8. PUBLICLY AVAILABLE DATA

The State Climate Office of NC from NC State University provided climate data (daily average outdoor temperature, RH, and dew point) from the three weather stations nearest to participating schools- Castle Hayne, Wilmington, and Chapel Hill (114). These data were sent to the researcher in Excel spreadsheets and imported into SAS (111). After importing the data, the researcher randomly checked 10% against the original Excel files for accuracy.

School employee demographics were downloaded in Excel format from the NC Department of Public Instruction website (133). The researcher analyzed these data in Excel for comparison between the target population and the study population.

4.9. DATA STORAGE AND PROTECTION

The researcher removed all potential identifiers including any IP or email addresses, and only study IDs remained in all SAS databases. The original health surveys, classroom inspections, and study roster were password protected, encrypted, and stored as zipped files on the researcher's laptop and on an encrypted flash drive. The researcher changed passwords for the study laptop and flash drive every three months, using UNC ONYEN security requirements for password creation. All paper copies of study materials were stored in two locked file cabinets in a locked office suite owned by the UNC Epidemiology Department. For confidentiality purposes, the researcher placed consent and contact information forms in a separate cabinet from any health surveys and walkthrough inspection reports.

5. METHODS: DATA ANALYSIS

5.1. INTRODUCTION

The objectives of this dissertation were to examine the relationship between school building structural factors and classroom RH levels, as well as to study the impact of RH control on teachers' health outcomes. Therefore, the outcome of Aims 1a and 1b (RH) was used as the exposure for Aim 2 analysis. As collected, data were clustered on many levels-- time within individual classroom/ participant, individuals within buildings, buildings within schools, and schools within districts. Methods to account for this clustering were utilized in analysis whenever the sample size and data structure allowed. The following section will describe the data structure in detail and outline the analysis methods.

5.2. CLASSIFICATION VARIABLES AND DATA STRUCTURE

Data were collected on several levels (Table 5.1). Time-variant data included outdoor and indoor temperature and humidity, WHD data, building occupancy, classroom dehumidifier use, season, date, and time. Time-invariant variables included classification variables, (cross-sectional) walkthrough inspection data, enrollment survey data, and HVAC survey data.

TABLE 5.1. CONCEPTUAL DATA LEVELS FOR AIM 1

Level	Other Variables Measured at this Level	N (Unique)
	Time invariant	
District	None	2
City	None	3
School	HVAC maintenance	10
Building	Any signs of water damage, building age (categorical)	22
Classroom	All HVAC variables	233 inspected, 134 monitored with hygrometers, 129 both monitored and inspected
Participant	All demographic variables	122
	Time variant	
Time	Season, phase, date, week number, time	3 seasons; 2 phases; 31 weeks; 188 days; 96 time points
District	None	2
City	Mean daily outdoor temperature and humidity	3
School	Scheduled occupancy	10
Building	None	22
Classroom	Indoor temperature (^{o}C) and relative humidity (%) (every 15 minutes)	134 classrooms included in analysis; 9044 classroom- days; >18048 classroom-observations
Participant	Work hours; symptom data; medication and classroom dehumidifier use (Phase 1= weekly; Phase 2=daily)	122

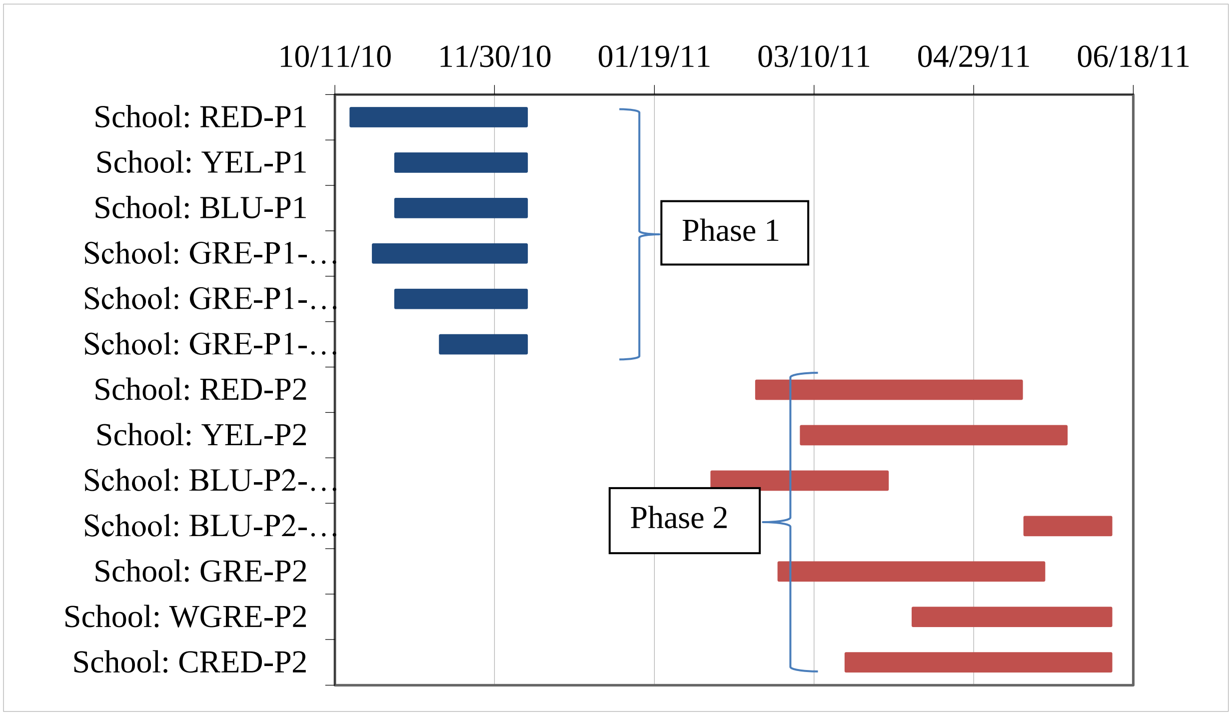
School was a nominal, categorical variable created by assigning a prefix that corresponded to the color coding used on the survey drop boxes for each school, plus a suffix denoting the study phase (ex: "BLU-P1"). Building was a nominal, categorical variables created by concatenating the building name with the school code to create a unique identifier for each building (ex: "BLU-P1 Main Building"). Classroom identification numbers were created by concatenating classroom name/ number and school code (ex: "300_BLU-P1"). Classroom ID was the subject-level identifier for the Aim 1 analysis. Participant ID was the subject-level identifier for the Aim 2 analysis.

Time was measured in seconds in military time. Hygrometer measurements were recorded every 15 minutes. Date was measured by calendar date from 00:00:00 to 11:59:59. Since enrollment was staggered and follow-up length varies, a new date variable was created, centered on date of first observation for each participant ID (day= 0).

Season was based on the solstice and equinox dates for 2010 and 2011 from the US Naval Observatory (134). Autumn was from September 23, 2010 to December 20, 2010. Winter was from December 21, 2010 to March 19, 2011. Spring was from March 20, 2011 to June 20, 2011. No data were collected in the summer.

The wave of data collection of each participant was indicated by the dichotomous variable "Phase." Phase 1 started in the first enrolled school on October 16, 2010 and ended for all schools on December 10, 2010. Phase 2 started for the first enrolled school on February 6, 2011 and ended between May 14 and June 11, 2011, depending on the school (Figure 5.1).

FIGURE 5.1: FOLLOW-UP SCHEDULE FOR EACH SCHOOL



5.3. DEPENDENT VARIABLES

Table 5.2 provides an overview of the dependent variables that are detailed in the following sections. Continuous RH was used only in the imputation for Aim 2. Polytomous RH was used as an independent rather than dependent variable in Aim 2.

TABLE 5.2. DESCRIPTIONS OF DEPENDENT VARIABLES

Variables	Range	Levels	Time scale	Instrument Used for Measurement	Analysis Aim 1a	Analysis Aim 1b	Analysis Aim 2
Continuous Relative Humidity (RH)	0-100%		15-minute intervals and daily average	Hygrometer	X		X
Dichotomous RH		0= not within recommended level 1= within recommended level	Daily average	Hygrometer	X	X	
Polytomous RH		<30%=low 30-50%= recommended >50%= high	Daily average	Hygrometer		X	X
Any Asthma Symptoms		0= no 1= yes	Daily	Weekly Health Diaries			X
Any Cold/Allergy Symptoms		0= no 1= yes	Daily	Weekly Health Diaries			X

5.3.1. Aims 1a and 1b-Indoor Relative Humidity

Continuous relative humidity (RH) -- measured every 15 minutes-- was averaged over a 24-hour period to create variables for continuous mean daily RH and standard deviation of the mean daily RH, so that this variable was on the same time scale as the daily symptom data for Aim 2. For Aim 1a, the researcher was interested in examining the ability of schools to maintain daily average classroom RH levels within the recommended level (30-50%) for comfort and asthma trigger control (51). A dichotomous variable was created categorizing the daily mean RH as within (30-50%) versus not within (<30% or >50%) the recommended level. This variable was used only for Aim 1a. For Aim 1b, the researcher was interested in examining building factors that affected RH levels. However, a dichotomous variable was not sufficient to investigate patterns leading to RH above versus below the recommended level. Thus, a three level, nominal categorical variable was created for daily mean RH <30% (low), 30-50% (recommended), or >50% (high). Since a high average RH was likely to have different health implications than a low average RH, the researcher chose the polytomous RH variable as the exposure for Aim 2 analysis (22, 29, 56). See Table 5.2 for descriptions of these variables.

5.3.1.1. Missing Relative Humidity Data

The researcher checked for completeness of the data both with respect to the number of days with any observations and the number of observations recorded in each day. The hygrometers recorded data every 15 minutes (4 times per hour); thus, a "complete day" should have had 96 temperature and humidity observations. An "incomplete day" was any day with < 96 observations. A "missing day" was a day with no observations. Table 5.3 lists reasons for incomplete data and the number of observations in each reason category.

The hygrometers malfunctioned because they fell off of the wall, most likely because the adhesive backing to the hooks did not work or the students knocked the machines off of the wall. Adhesive backing failure could be due to high humidity or to the wall's surface material or texture. Since missing data from hygrometer malfunctions could have been related to RH level, the researcher compared distributions of data completeness with relationship to RH (135).

The distributions of continuous mean daily RH were very similar for complete (μ=42.7, σ= 12.8) versus incomplete days (μ=42.3, σ=13.4). The dichotomous mean daily RH distributions are statistically different between complete versus incomplete days. RH from incomplete days was more likely to be within the recommended level than RH from complete days (RR=0.98 [0.97, 0.99]. However, this difference seemed unlikely to create any meaningful bias since the proportion of missing data was small (0.33% of total classroom-days).

Missing classroom-days were removed from the Aim 1 dataset, since they did not offer any information. Incomplete classroom-days were kept in the dataset, and the mean RH from these days was calculated using the same method as for complete days.

TABLE 5.3. REASONS FOR MISSING AND INCOMPLETE DAYS

Category	Reason	N obs/ day	N classroom-days
Missing days	Hygrometers malfunctioned.	0	22
Complete days	Procedures followed as specified.	96	8486
Incomplete days	Hygrometer timing was off by one second.	95	175
	Hygrometer malfunctioned and some, but not all observations were lost.	4 to 90	8
	First or last day of data collection	9 to 94	405
Total days	Classroom-day observations	0 to 96	9074

5.3.2. Aim 2: Dichotomous Health Outcomes

The two dichotomous health outcomes—any asthma symptoms and any cold or allergy symptoms—were composed of answers to several questions in the WHD. Each week, participants were asked the screening question, “Did you have any breathing problems this week?” Participants who answered “yes” were led to a list of asthma symptoms and asked to check off any days in which they experienced each symptom. If the participants skipped the screening question for that day, then the dichotomous outcome variable AnyAsthSympt was coded as missing. If the participants answered the screening question “no” or did not check off any symptoms, then AnyAsthSympt was coded “0.”AnyAsthSympt was coded “1” if the participant checked off any of the following symptoms on that day: wheezing, chest pain, tightness in chest, shortness of breath, or dry cough. Because most participants would not think of this symptom as being related to a breathing problem, “Dry cough” was an option given under the screening question “Did you have any other health problems this week?”

Next, participants were asked, “Did you have any cold/flu/sinus/allergy symptoms this week?” Because cold and allergy symptoms are virtually indistinguishable, the researcher combined them into one outcome variable. However, since influenza was not the subject of this analysis, the researcher excluded any observations that indicated an influenza-like illness. The medically accepted definition for influenza-like illnesses is a fever with cough and/or sore throat (136). Therefore, if the participants answered the screening question “no,” did not check off any symptoms or checked off symptoms that included fever with cough or sore throat; then the dichotomous outcome variable ColdAllerAny was coded “0.” If the participants skipped the screening question for that day, then ColdAllerAny was missing. ColdAllerAny was coded “1” if the participant checked off any of the following symptoms on that day (with no influenza like illness): productive cough; itchy eyes; itchy, scratchy throat; stuffy nose; runny nose; sneezing; or sore throat.

Participants also had the option of writing in other symptoms under “other breathing problems” including bronchitis, cough (no description), sinus congestion/stuffy nose, sore throat, stomach ailment. Under “other cold/ allergy/ flu symptoms,” participants wrote in the following additional symptoms: extremely dry nasal passages, low grade fever, nasal drip in throat, sinus headache/ pressure, congestion, cough (non-productive), cough (no description), earache, stomach flu, nosebleed, sinus infection, watery eyes, swollen neck glands. However, the researcher decided not to include symptoms written in by participants in analysis since the descriptions were either not specific enough to classify or were identical to symptom choices presented to the participants later in the survey.

5.4. INDEPENDENT VARIABLES

5.4.1. Measures of Ventilation

The originally proposed measure of ventilation was classroom carbon dioxide (CO_2) level. Indoor CO_2 concentrations were difficult to measure because they were a function of occupancy and ventilation rate, both of which were variable over time. For this pilot study, we did not have the funding necessary to purchase data logging CO_2 monitors; however, we were able to borrow point monitors for the walkthrough inspection. CO_2 concentrations revealed something about the relative CO_2 concentrations between classrooms during the inspection. However, these measurements may have overestimated the ventilation rates of occupied classrooms because they included unoccupied classrooms and air exchange from areas such as hallways (5). Classroom occupancy was recorded at the time of CO_2 measurement to allow for adjustment by classroom usage. Since cross-sectional CO_2 level was not a good predictor of true classroom ventilation during follow-up, it was not considered for analysis.

During the walkthrough inspection, the researcher noted whether the HVAC was off or broken for each classroom. Participants typically turned the HVAC off if the fan was so loud that it interfered with students' abilities to hear classroom lectures. Though this information was collected only on the day of the inspection, having an HVAC system in disrepair indicated a more permanent ventilation problem than having a high CO_2 level. This problem most likely persisted for most of follow-up, so this variable was included in the analysis as a dichotomous variable indicating a working ("0") versus broken or shut down ("1") HVAC.

Additionally, information was collected during the inspection on how many classrooms shared one ventilation source. A nominal categorical variable was created to indicate whether classrooms had an individual ventilation source or shared between 2, 3-4, or more than 6 classrooms. Based on advice from an engineer from the NC Department of Public Instruction, the researcher did not include this variable in the main analysis, since each HVAC unit should be commissioned to supply sufficient ventilation for the appropriate number of classrooms. Therefore, this would not have been an accurate proxy measure of ventilation.

The following covariates related to ventilation with a potential impact on RH were collected as part of the HVAC survey: programmed setback, heating/ cooling set points, economizer, fresh air dehumidification on intake, any dehumidification, cooling mechanism, and fresh air control. Programmed setback was a dichotomous variable created to indicate whether the classroom HVAC system temperature or humidity set point was programmed or manually changed to save energy during unoccupied hours. Though reducing ventilation during unoccupied hours saves energy, it also has the potential to increase classroom humidity by allowing air to stagnate during times when custodial staff may be mopping floors.

Heating and cooling set points for both unoccupied and occupied hours were also collected as continuous variables measured in degrees Fahrenheit. However, in the case where HVAC thermostats were manually controlled, the set point was unknown and probably highly variable throughout the day. Due to the uncertainty inherent in the set points for some classrooms, they were not used in the main analysis.

Another ventilation related variable which was collected but not used during main analysis was the trigger to change the HVAC from heating to cooling mode. This was a nominal variable with the categories indoor temperature, outdoor temperature, and manually switched. In classrooms with a manually switched HVAC, the mode was not often changed until necessary and then could not easily be changed back to the previous mode since it required calling in a professional. Operating in the wrong mode could reduce ventilation and comfort, since the temperature may not trigger the fans to run. However, since it was only potentially useful at two time points during the year, this variable was left out of the analysis.

A dichotomous variable was created to indicate the presence (1) or absence (0) of an economizer in each HVAC system. An economizer may be added onto an HVAC system to vary the outdoor air damper positions depending on outdoor temperature relative to the indoor temperature to save energy by increasing or decreasing the fresh air flow, as necessary (137). When fresh air dampers are closed or nearly closed, fans recirculate indoor air through classroom ducts. This variable was used in analysis.

In locations where outdoor humidity is constantly high, economizers may greatly increase indoor humidity if fresh air is not dehumidified. Therefore, the researcher also collected information on whether or not fresh air was dehumidified on intake. Additional information was collected for analysis about whether the HVAC systems offered any dehumidification through normal cooling mechanisms or additional built-in dehumidification processes.

HVAC systems in schools typically use one of a handful of cooling mechanisms—direct expansion (DX) split system, traditional heat pump with refrigerant cooling, or chilled water system. A nominal categorical variable was created to record the type of system used for each classroom. This variable was converted to a group of indicator variables for analysis. For the chilled water systems, information was also collected on whether they were two or four pipe systems; however, this variable was not used in analysis since it only applied to a handful of systems. Differences exist between all of the above systems as far as the cost, efficiency, maintenance needed, and built-in dehumidification ability.

Lastly, the HVAC survey collected information on how fresh air flow was controlled for each system. A nominal categorical variable was created to record the fresh air damper control mechanisms including thermostat, CO_2 monitor, manual operation, operation on a time schedule, or leaving the dampers open all of the time. This variable was converted to a group of indicator variables for analysis. Because there were such a small number of observations in classrooms with manual damper operation, this category was combined with the category "operation on a time schedule." This variable was originally included in analysis, but was removed because it yielded unstable estimates due to small sample sizes in the remaining categories.

5.4.2. Maintenance Practices

Several variables were collected regarding school maintenance practices, including HVAC maintenance frequency, toxicity and type of cleaning supplies, frequency of air filter changes, custodial staffing ratios, and use of maintenance logs and IPM programs. However, only HVAC maintenance frequency was expected *a priori* to have any effect on indoor RH.

HVAC maintenance frequency was determined at the walkthrough inspection for each school by asking the district maintenance liaison how often scheduled maintenance and inspections were performed on the HVAC systems. Frequencies reported were quarterly or annually scheduled maintenance or maintenance as needed. HVAC maintenance frequency was a nominal categorical variable, converted to indicator variables for the main analysis.

5.4.3. Water Damage

Water damage in the classroom can be caused by condensation from high RH or may be an indicator of another source of classroom dampness. Classroom water damage was visually assessed during the walkthrough inspection. A dichotomous variable was created with the value of "1" if any of the following were found to be true for the classroom during the walkthrough inspection: history of flooding, any leaks, evidence of water damage on the ceiling (mold, rust, or water spots), water damage around the sink, household plants watered without anything to collect drainage, and any other signs of condensation or water damage.

5.4.4. Building Age

Although contested amongst engineers, building age may reflect trends in building techniques, building materials, and building envelope permeability and may be an indicator of HVAC system age and indoor air pollutant mixture (64). During the walkthrough inspection, school building age was determined by asking the maintenance or school liaison in what year the building was completed. In some cases, an addition was built onto an existing building, so building age was linked to classroom rather than building name. Building age was categorized by decades (0-10, 11-20, 30-40, 40-50, and >50 years old) using indicator variables for analysis.

5.4.5. Climate Variables

The NC State Climate Office provided outdoor RH and temperature averaged daily from October 20, 2010 to June 14, 2011, as well as the daily minimums and maximums (24). These data were merged with indoor humidity and temperature data by city of school.

Heating and cooling days were defined using daily average outdoor temperatures that were estimated to(138)(Brager and de Dear 2001) produce indoor temperatures within 80% of the Adaptive Comfort Standards created by Brager, et al. for a naturally ventilated building (138). These outdoor temperatures were used as guides for when heating and cooling would be requested in mechanically ventilated buildings as follows: heating days= less than 15^{o}C, transition days= 15-23^{o}C, cooling days= more than 23 ^{o}C. The researcher created the categorical variable for heating/ cooling season by converting average daily outdoor temperatures from Fahrenheit to Celsius and then categorizing each day as heating, cooling, or transition.

Since RH is a function of temperature, only outdoor RH was used in Aim 1 analysis. Outdoor mean RH was roughly linearly related to indoor RH and so remained a continuous variable for analysis. However, since outdoor temperature changes can cause asthma exacerbation, outdoor temperature was included in Aim 2 analysis instead of outdoor RH.

5.4.6. Other Potential Covariates

Classroom (free-standing) dehumidifiers may be used in classrooms with known water damage to dry out the damaged materials. They may also be used in classrooms with perceived high RH to remove excess moisture from the air. Most dehumidifiers are equipped with a hygrostat, which turns the dehumidifier off when the air reaches the desired humidity level. Classroom dehumidifier use was noted in the walkthrough inspection and in the WHD. Phase 1 participants were asked about weekly dehumidifier use in the WHD, but Phase 2 participants were asked about daily use. Therefore, a new variable was created to standardize the measurement time between the two phases to weekly measurement, coded as "1" if any classroom dehumidifier use was reported for that week, on any day of the week. Most participants (92.6%) had either no dehumidifier use at all or used the dehumidifier each week. Since there were not many discordant pairs, we were not able to compare the effects of using vs. not using dehumidifiers within classrooms.

Since water vapor from people exhaling and occupants' activities involving water or wet materials had potential to increase RH, information was collected as to the school's occupancy schedule based on the district calendar and school time schedule for the 2010-2011 academic year. Schools were classified as occupied starting from an hour before school opened and an hour after school ended each day to allow for staff or student meetings, preparation, or other extracurricular activities. All other hours of the day, including all hours on weekends and school holidays (not including teachers' workdays) were classified as unoccupied. Since RH was averaged for each day for Aim 1 analysis, each day was categorized as occupied if there were any occupied hours and unoccupied if the school was not occupied at all that day.

Independent variables only considered in the models for Aim 2 analysis included gender; window opening behavior; mold, dust mite, and pollen allergies; participants' presence at school; and cold/ allergy medication use. Since window opening behavior and cold/ allergy medication use was collected only weekly in Phase 1 compared to daily in Phase 2, these variables were changed to weekly summary variables for Phase 2 participants where the week was coded as "1" if the participants had any day with this behavior. Gender and mold and dust mite allergies were used directly as asked on the enrollment survey. Pollen allergies were coded as "1" if the participant reported "allergies to pollen-spring," "allergies to pollen-fall," or wrote in other allergies that fit under this category (i.e. Ragweed). A variable was created from the number of self-reported work hours, to indicate the participants presence (worked >0 hours on a given day) or absence (worked 0 hours for a given day) from the school building each day. Saturdays and Sundays were assumed as absences, since the researcher did not request participant work schedules for these days to avoid confusion among people working at home on weekends. On days coded as absent, participants were assumed to be unexposed to classroom RH for that day.

5.5. UNIVARIATE AND MULTIVARIATE DATA ANALYSIS

All of the following analyses were completed in SAS V9.3 (111).

5.5.1. Analysis: Aim 1a

The researcher estimated the proportion of classrooms with controlled RH [daily average RH within the recommended range (30-50%)], stratified by school and month. The numbers of classroom-days of follow-up were entered into two small datasets—one containing all classroom-days with controlled RH and the other containing all classroom-days with uncontrolled RH. The two datasets were merged and the percent of days with controlled RH were calculated and stratified by school and month for univariate analysis.

The distributions of all classroom RH observations, stratified by phase and school, were plotted by day using box plots. Recommended RH levels were indicated on these graphs as well. Indoor daily average temperature (^{o}C) was overlaid onto these graphs for comparison.

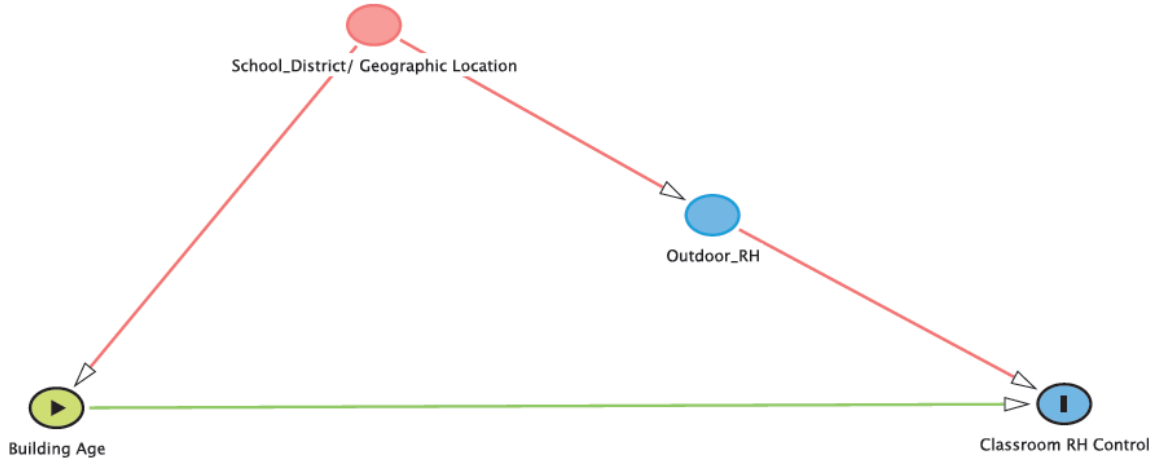
5.5.2. Analysis: Aim 1b

5.5.2.1. Introduction

The main objective of Aim 1 analysis was to provide evidence for actionable recommendations that school administrators could implement to improve classroom humidity control. Based on this objective, the analysis was not focused on one causal relationship between a main exposure and outcome. Instead, several independent variables were of interest as important exposures to examine. Also, time was unbalanced in this study because of missing data and differing lengths of follow-up times between and sometimes even within schools, by design (135). Therefore, the researcher chose methods that could accommodate unbalanced longitudinal data. However, with a small number of clusters (buildings) and a complex data structure, the complex relationships between building-related factors caused model convergence problems when put into one large model.

Since the researcher was interested in estimating the effects of several covariates, all equally important to the study aims, nine small models were created to separately estimate the effect of each exposure on classroom RH control. These models were represented by the following directed acyclic graphs (DAGs), including only potential confounders and excluding mediators or colliders. Once these models were represented in DAGs, the researcher chose the minimally sufficient set. If there were several possible minimally sufficient sets, the set using variables with more accurate measurement was chosen (i.e. "HVAC off/broken" was directly measured for each classroom during the walkthrough inspection and so was considered more accurately measured than "maintenance funds" approximated from district level economic indicators). The researcher illustrated the final models shown in Figures 5.2-5.10 using the web-based causal diagram program, DAGitty (139).

FIGURE 5.2. DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN BUILDING AGE AND CLASSROOM RELATIVE HUMIDITY (RH) CONTROL (MODEL 1)



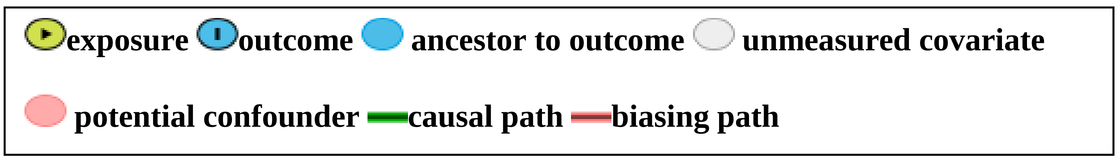


FIGURE 5.3. DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN WATER DAMAGE AND INDOOR RELATIVE HUMIDITY (RH) CONTROL (MODEL 2)

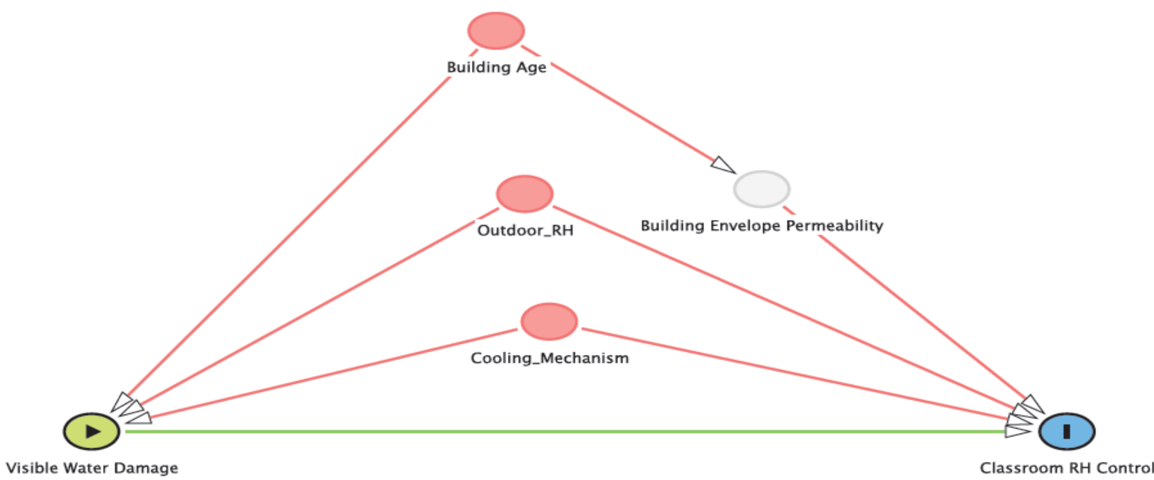


FIGURE 5.4. DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN FREQUENCY OF HVAC MAINTENANCE AND INDOOR RELATIVE HUMIDITY (RH) CONTROL (MODEL 3)

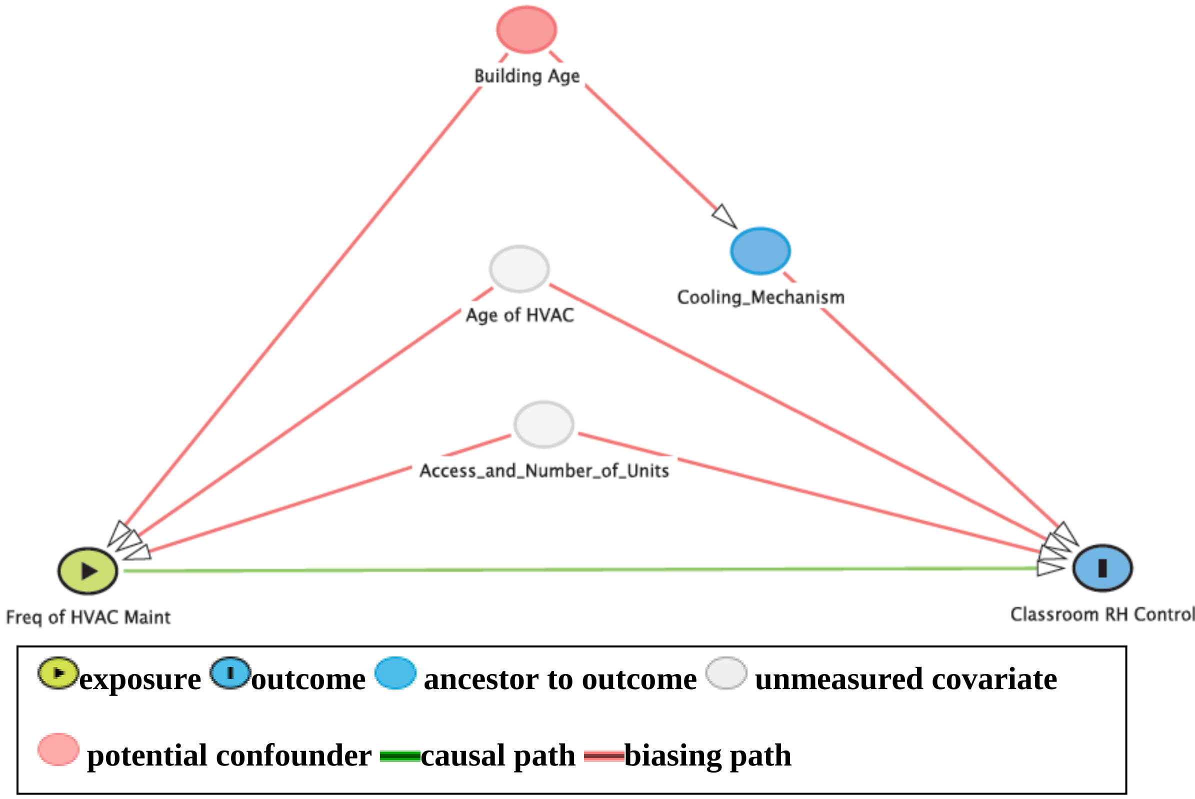


FIGURE 5.5. DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN FRESH AIR DEHUMIDIFICATION AND CLASSROOM RELATIVE HUMIDITY (RH) CONTROL (MODEL 4)

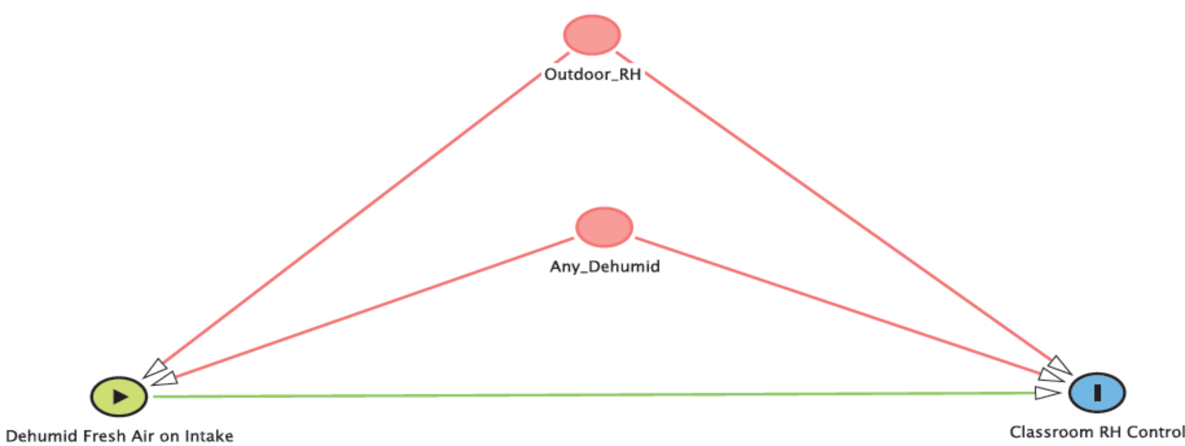


FIGURE 5.6. DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN COOLING MECHANISM AND CLASSROOM RELATIVE HUMIDITY (RH) CONTROL (MODEL 5)

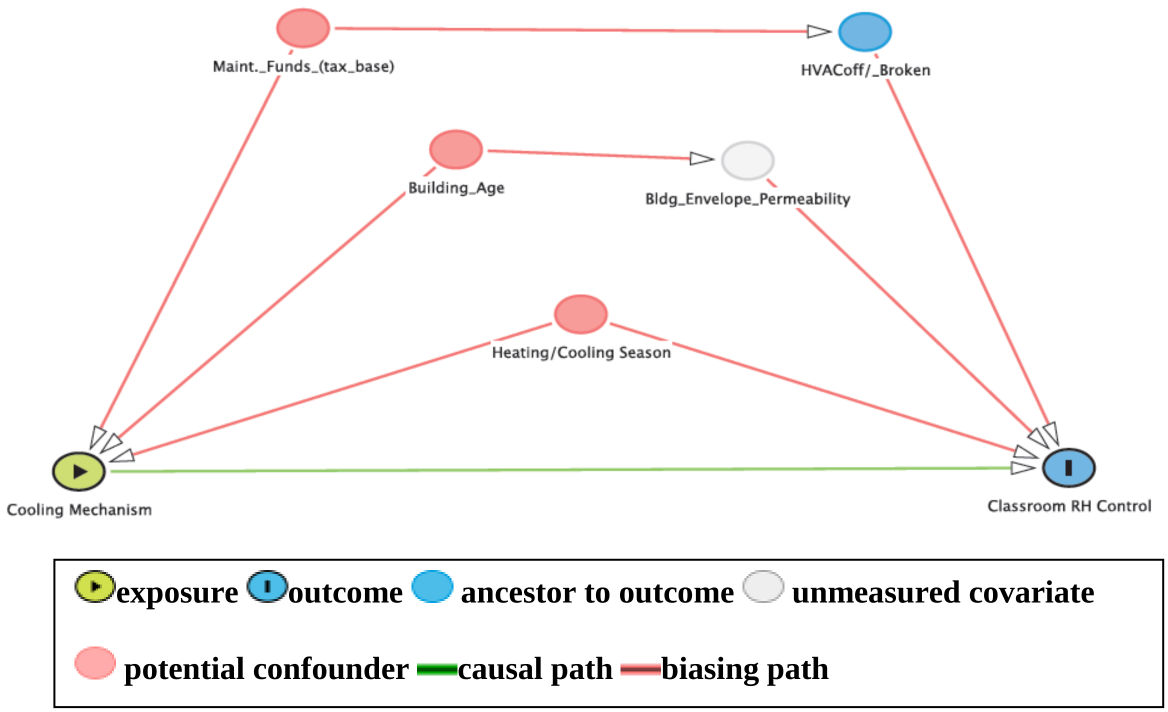


FIGURE 5.7 DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN ECONOMIZER AND CLASSROOM RELATIVE HUMIDITY (RH) CONTROL (MODEL 6)

FIGURE 5.8 DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN ROOM DEHUMIDIFIER AND CLASSROOM RELATIVE HUMIDITY (RH) CONTROL (MODEL 7)

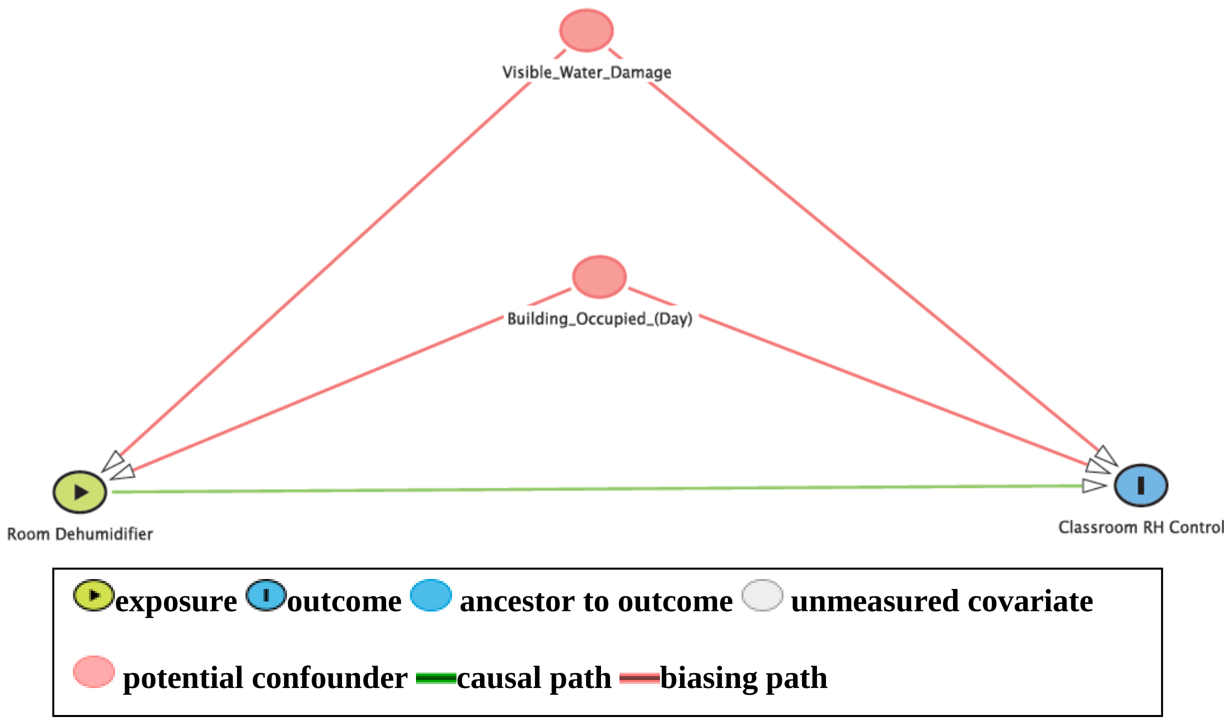


FIGURE 5.9. DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN SETBACKS AND CLASSROOM RELATIVE HUMIDITY (RH) CONTROL (MODEL 8)

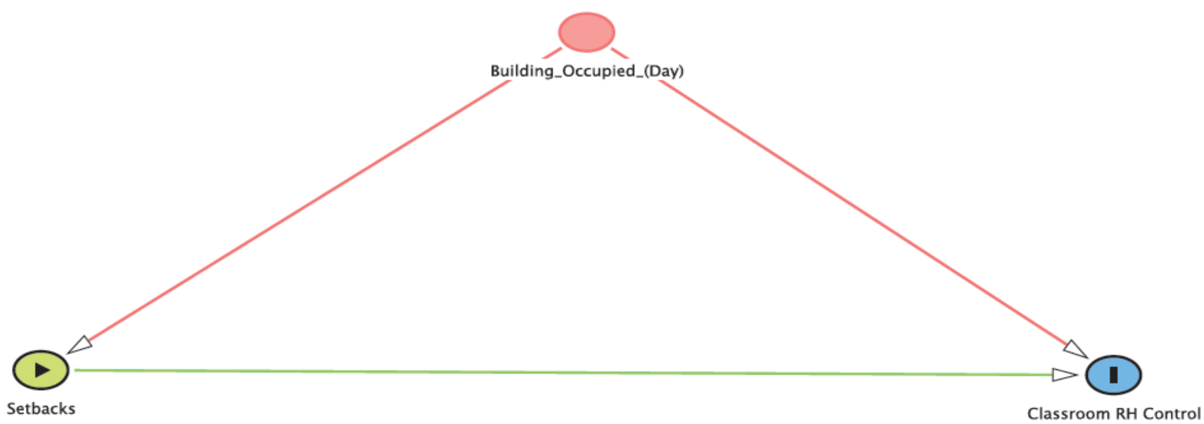
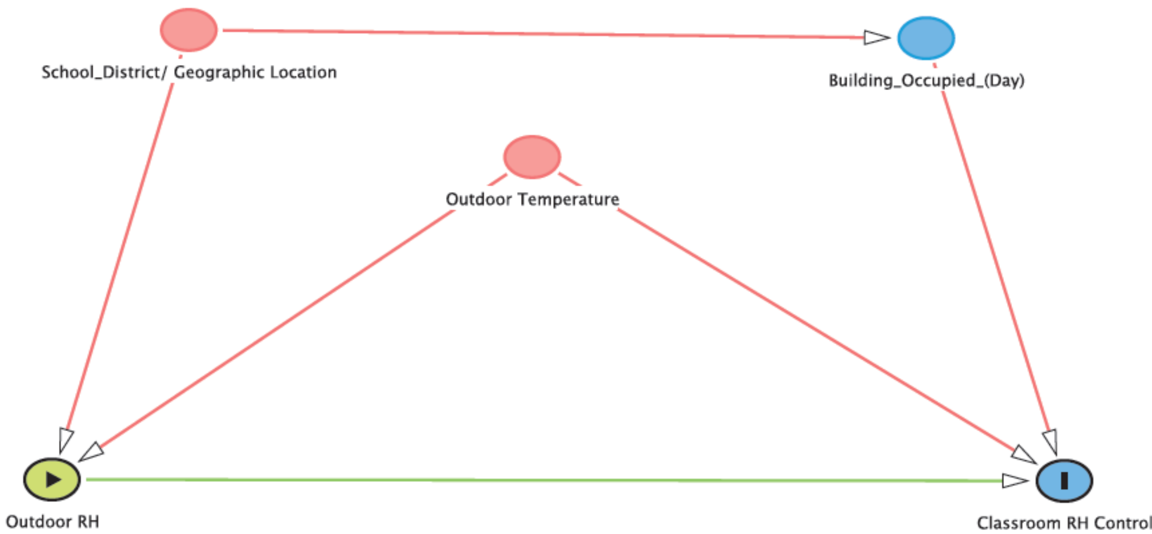


FIGURE 5.10. DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN OUTDOOR RH AND CLASSROOM RELATIVE HUMIDITY (RH) CONTROL (MODEL 9)



5.5.2.2. Polytomous Relative Humidity Models

Since this was a prospective cohort study and risks were more practically interpretable for this outcome than rates, the researcher chose to use risk ratios as the measures of association between RH and building factors. The baseline risk of having uncontrolled RH was large [R_1= 0.50 (0.47, 0.53)], further supporting this choice (140).

Initially the relationship between building/structural factors and dichotomous RH control was calculated. Since the relationships between the pairs of RH categories violated the proportional odds assumption (β_k=β; where k=outcome levels), a nominal polytomous response was used to categorize RH instead of the ordinal response. The SURVEYLOGISTIC procedure (SAS software, Version 9.3) was used to estimate generalized logits (g-logit link, multinomial distribution) for a nominal polytomous outcome Y_{it} defined below (Equation 5.4). I clustered the data by classroom and used the Taylor series method for variance estimation of complex survey data. Multivariate models included all potential confounders from DAGs in Figures 5.2-5.10.

$$\log\left[\frac{\Pr(Y_{it}=g|x)}{\Pr(Y_{it}=1|x)}\right]=\hat{\beta}_{0g}+\hat{\beta}_{ng}x_{nit} \quad \text{(Equation 5.4)}$$

where g= outcomes 2 or 3; x=observed exposure data, n=number of covariates, t=time(days), i=individual classroom

I then fit more complex univariate and multivariate models using Generalized Linear Mixed Models to account for clustering by both classroom and building (Equations 5.5-5.8). Due to issues with model convergence using the nominal polytomous outcome, two separate models were fit using a logit link for comparison to the estimates from the simpler polytomous models. Laplace estimation methods were used to reduce small sample size bias due to the small number of buildings. The residual degrees of freedom were divided into between-subject and within-subject which allowed fixed effect changes within subject to be estimated.

Time dependent covariates, fit to the models represented in Equations 5.5 and 5.6, included outdoor RH, season, dehumidifier use, and building occupied. Time independent covariates, fit to the models represented in Equations 5.7 and 5.8, included school district, HVAC maintenance frequency, any dehumidification, programmed setbacks, economizer, fresh air intake, water damage, HVAC broken, cooling mechanism, and building age.

$$\log\left[\frac{\Pr(Y_{it}=g|x)}{\Pr(Y_{it}=1|x)}\right]=\hat{\beta}_{0ir}+\hat{\beta}_{n}x_{1irt}+\hat{\beta}_{mr}x_{1irt}+e_{tir} \quad \text{and } \hat{\beta}_{0ir}=Zu_i+Zu_{ir} \text{ (Equation 5.5)}$$

where x=observed data/fixed effects, n=number of fixed slope covariates, m=number of random slope covariates, u=index of clusters with u_i=classroom level variation and u_{ir}= building-level variation, t=time(days), i=individual classroom, r=number of buildings, e_t= residual variation due to time (day); $e\sim N(0,\sigma^2)$, $u_i\sim N(0,G_i)$, $u_{ir}\sim N(0,G_{ir})$

$$\log\left[\frac{\Pr(Y_{it}=g|x)}{\Pr(Y_{it}=1|x)}\right]= \hat{\beta}_{0ir}+\hat{\beta}_{n}x_{1irt} + \hat{\beta}_{mr}x_{1irt}+e_{tir} \quad \text{and } \hat{\beta}_{0ir} =Zu_{i}+Zu_{ir} \qquad \text{(Equation 5.6)}$$

where x=observed data/fixed effects, n=number of fixed slope covariates, m=number of random slope covariates, u=index of clusters with u_i=classroom level variation and uir= building-level variation, t=time(days), i=individual classroom, r=number of buildings, e_t= residual variation due to time (day); $e\sim N(0,\sigma^2)$, $u_i\sim N(0,G_i)$, $u_{ir}\sim N(0,G_{ir})$

$$\log\left[\frac{\Pr(Y_{it}=g|x)}{\Pr(Y_{it}=1|x)}\right]= \hat{\beta}_{0ir}+\hat{\beta}_{1}x_{1ir} +e_{tir} \quad \text{and } \hat{\beta}_{0ir} =Zu_{i}+Zu_{ir} \qquad \text{(Equation 5.7)}$$

where x=observed data/fixed effects, u=index of clusters with u_i=classroom level variation and u_{ir}= building-level variation, t=time(days), i=individual classroom, r=number of buildings, e_t= residual variation due to time (day); $e\sim N(0,\sigma^2)$, $u_i\sim N(0,G_i)$, $u_{ir}\sim N(0,G_{ir})$

$$\log\left[\frac{\Pr(Y_{it}=g|x)}{\Pr(Y_{it}=1|x)}\right]= \hat{\beta}_{0ir}+\hat{\beta}_{1}x_{1ir} +e_{tir} \quad \text{and } \hat{\beta}_{0ir} =Zu_{i}+Zu_{ir} \qquad \text{(Equation 5.8)}$$

where x=observed data/fixed effects, u=index of clusters with u_i=classroom level variation and u_{ir}= building-level variation, t=time(days), i=individual classroom, r=number of buildings, e_t= residual variation due to time (day); $e\sim N(0,\sigma^2)$, $u_i\sim N(0,G_i)$, $u_{ir}\sim N(0,G_{ir})$

5.5.2.3. Effect Measure Modification

The distributions of classroom RH observations taken every 15 minutes differed by both scheduled building occupancy and programmed thermostat setbacks. Though the mean observed RH during occupied times ($Mean_{occ}$=42.6, SD_{occ}=13.2) was almost equivalent to the mean observed RH during unoccupied times ($Mean_{unocc}$=42.7, SD_{unocc}=12.7), the standard deviation for the occupied times was greater than that during the unoccupied times. Classrooms in a buildings with thermostat setback ($Mean_{setback}$=42.8, $SD_{setback}$=12.8) had a higher mean RH than classrooms in buildings without thermostat setback ($Mean_{no\ setback}$=37.4, $SD_{no\ setback}$=12.7).The researcher hypothesized that these two variables would be related since thermostat settings are often changed to minimize heating or cooling loads during unoccupied times of the day. Therefore, the estimates of the association between thermostat setback and RH levels was stratified by occupied times and compared to unstratified estimates.

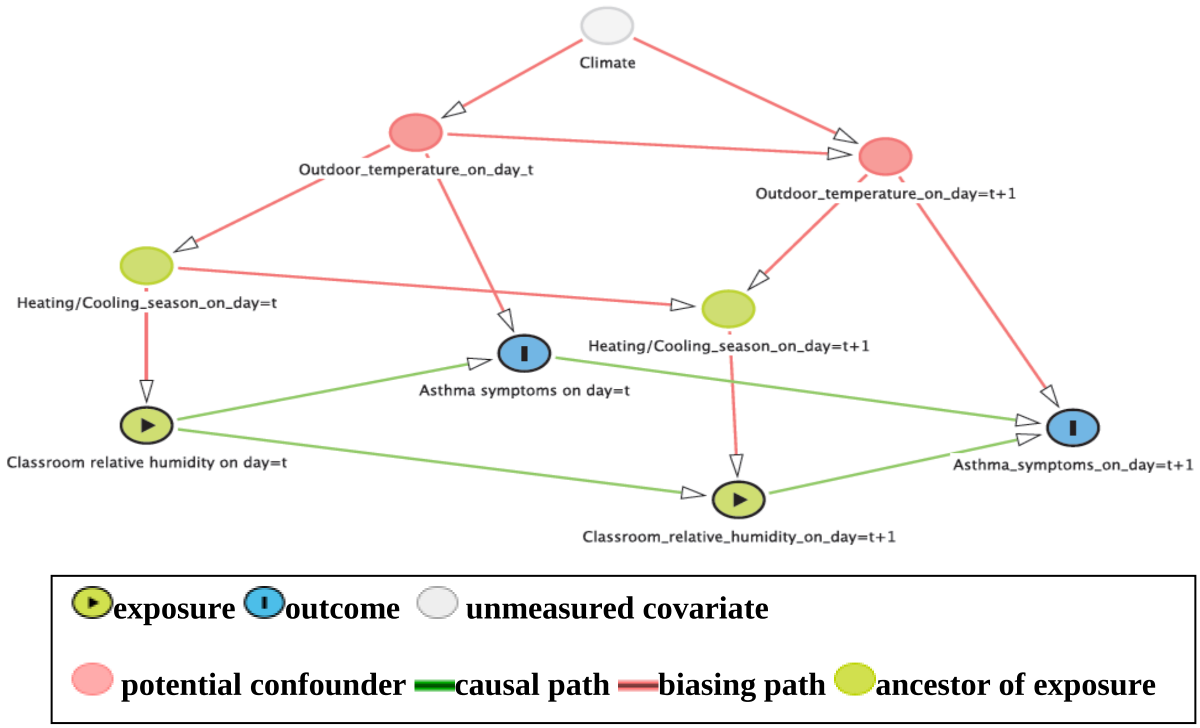
5.5.3. Analysis: Aim 2

5.5.3.1. Introduction

For Aim 2, the researcher was interested in estimating the unbiased effects of low (<30%) and high (>50%) compared to recommended (30-50%) daily average RH levels on any asthma symptoms and cold/ allergy symptoms among participants. However, since time-varying work schedules were not collected, the researcher limited Aim 2 analysis to RH observations from each participant's main classroom. If multiple classrooms were listed in the enrollment survey, the researcher defined the main classroom as the one where the participant worked for the majority of the day.

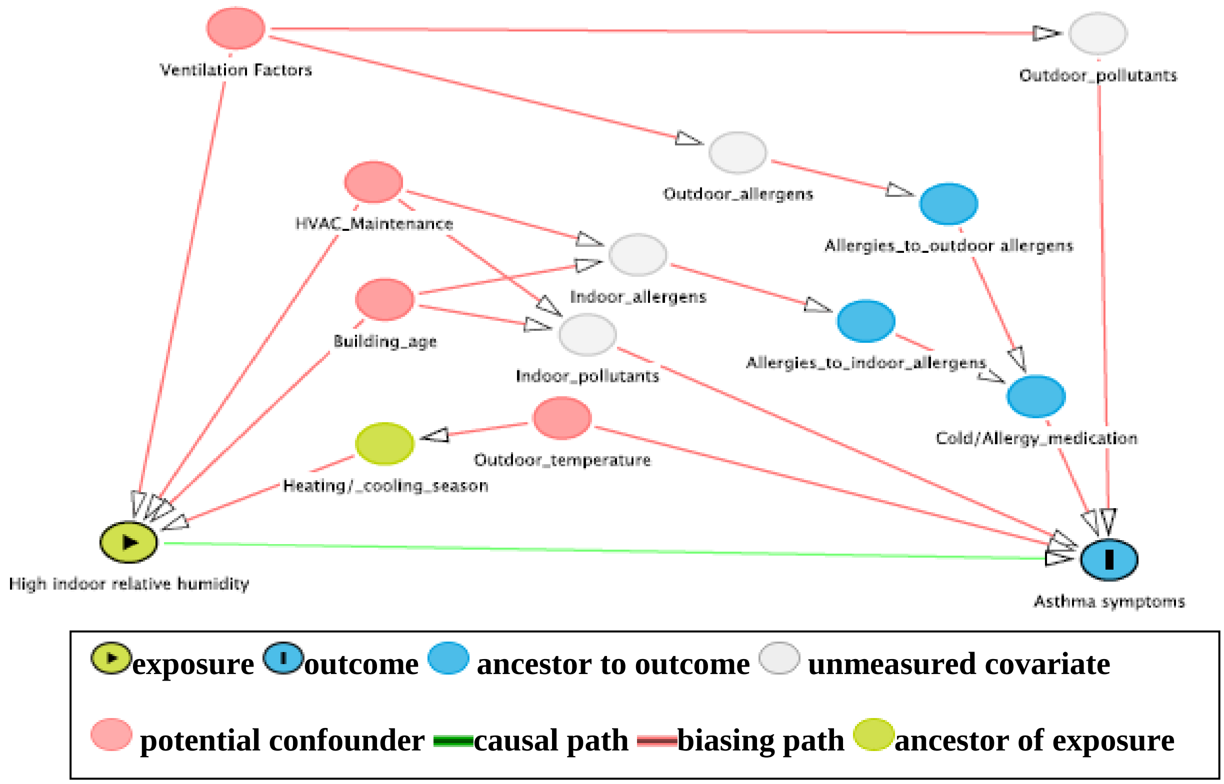
The researcher used the web-based causal diagram program, DAGitty to create Figures 5.11-5.14 (139). Outdoor temperature and heating/ cooling season were daily, time-varying covariates, entered into all Aim 2 models during model-building. I kept outdoor temperature in the final models for asthma symptoms. Figure 5.11 diagrams the conceptual relationships between time-varying convariates and the longitudinal main exposure and outcome.

FIGURE 5.11. TIME-VARYING COVARIATES FOR AIM 2



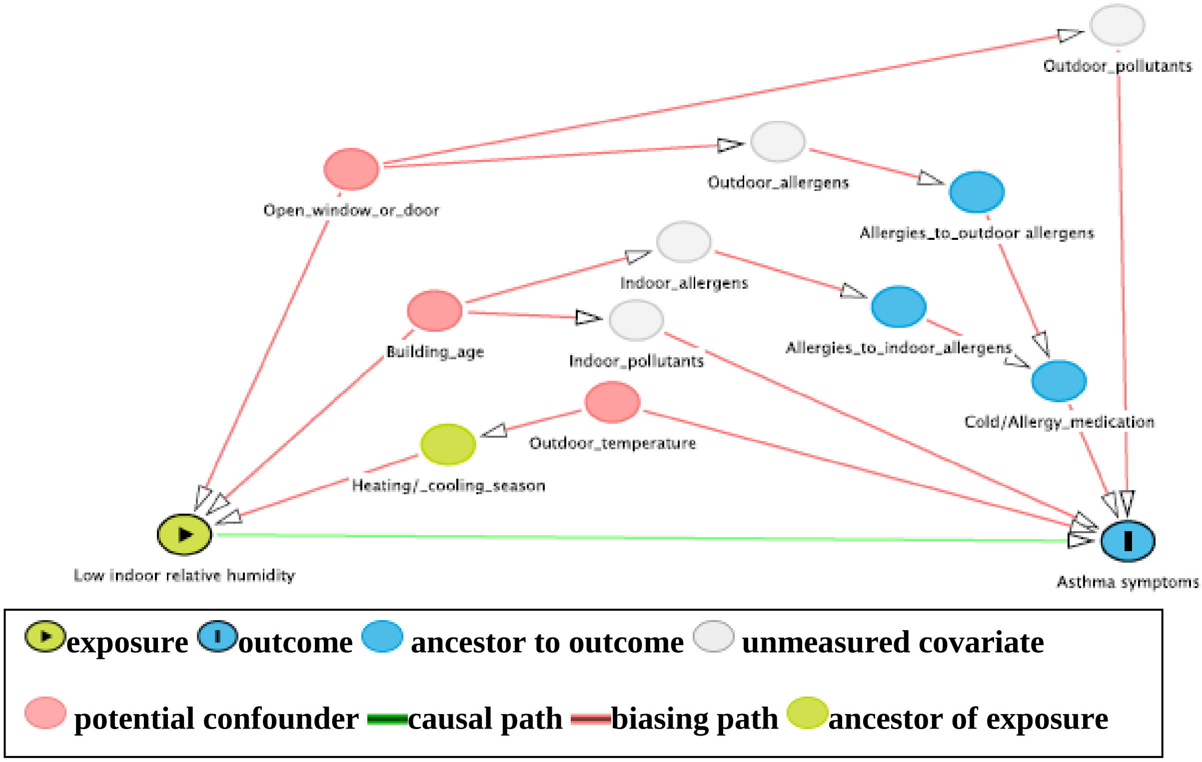
Since each outcome and RH level combination had a different set of potential confounders, a separate directed acyclic graph (DAG), including only potential confounders and excluding mediators or colliders, was created to represent each combination. The researcher chose the minimally sufficient set for adjustment based on these DAGs. If there were several possible minimally sufficient sets, the one using variables with more accurate measurement was chosen. For all models, a participant's presence at school on a particular day was also included as a potential effect measure modifier since the researcher hypothesized that estimates stratified by presence in the school environment would be heterogeneous, as presence at school may affect both exposure and perception of symptoms.

FIGURE 5.12. DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN HIGH INDOOR RELATIVE HUMIDITY AND ASTHMA SYMPTOMS (MODEL 1)



Asthma symptoms may be triggered by allergens, pollutants/ irritants, and cold outdoor temperature (Figure 5.12). Ventilation factors that can increase indoor RH and put participants in contact with outdoor allergens and pollutants include presence of an economizer, programmed thermostat setbacks, and window opening behaviors. HVAC maintenance and building age can increase indoor RH and put participants in contact with indoor allergens. Extreme outdoor temperatures may trigger asthma symptoms in susceptible individuals, and the cooling season was related to high RH in the analysis for Aim 1b. Therefore, heating/cooling season and outdoor temperature were considered separately as potential confounders. Outdoor temperature was chosen for the final model building, due to its direct and stronger effects on both the outcome and main exposure.

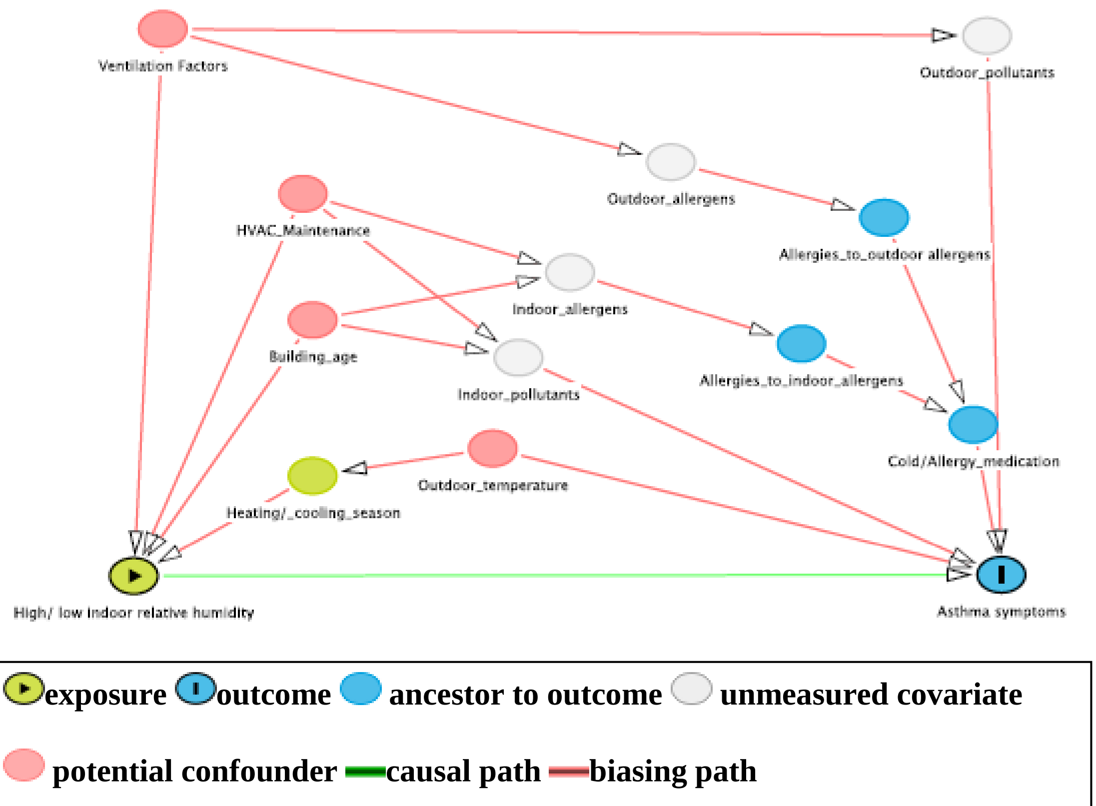
FIGURE 5.13. DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN LOW INDOOR RELATIVE HUMIDITY AND ASTHMA SYMPTOMS (MODEL 2)



To control for the unmeasured effects of indoor and outdoor pollutants on the association between low RH and asthma symptoms, building age and window/ door opening behavior were included in Model 2 as potential confounders (Figure 5.13). Phase 1 participants were asked about any medication use or window/ door opening during the week, rather than on specific days as in Phase 2. However, since it was important to control for window/ door opening behavior in this model, Phase 2 results were combined with Phase 1 results, after creating a weekly summary variable from Phase 2 daily data. Outdoor temperature was included as a potential confounder in the final model building. See Figure 5.11 for a discussion of this decision.

Classroom dehumidifier use also could cause low indoor RH and frequency of use is often influenced by the participants' allergies to indoor allergens. However, due to the relationship of allergies to indoor allergens to the other potential model covariates, dehumidifier use would have a cyclic relationship to low RH. In addition, this variable was also measured weekly in Phase 1 and daily only in Phase 2. Therefore, dehumidifier use was not considered as a potential confounder.

FIGURE 5.14. DIRECTED ACYCLIC GRAPH (DAG) FOR THE ASSOCIATION BETWEEN HIGH/ LOW INDOOR RELATIVE HUMIDITY AND COLD/ALLERGY SYMPTOMS (MODELS 3 & 4)



Building-related factors that can increase indoor RH and put participants in contact with outdoor allergens include presence of an economizer, programmed thermostat setbacks, and having an open window or door. A building-related factor that can increase indoor RH and put participants in contact with indoor allergens is HVAC maintenance. However, all confounding paths related to building factors can be blocked by controlling for either cold/ allergy medication or known allergies to indoor or outdoor allergens (Figure 5.14). The potential biasing pathways for the association between low indoor RH and cold/ allergy symptoms may have included symptoms developed in response to both infectious diseases and allergens, as with high RH (Figure 5.14). Proposed confounding pathways were similar for low and high RH.

Since participants were asked about daily cold or allergy medication use in Phase 2 only, the researcher chose to control for known allergies instead of medication use. Phase 1 participants were asked about any medication use during the week, rather than on specific days. Indoor RH can directly affect disease transmission rates and viral viability. However, since disease transmission rates were unmeasured, only the path through outdoor temperature is shown here as a potential confounder. Heating/cooling season (a categorical variable created from outdoor temperature) was also explored as a potential confounder to use in the place of continuous outdoor temperature; however, the continuous variables had a stronger effect on the association between RH and the respiratory outcomes. During the heating season, more so than the cooling season, human behaviors also may play a part in disease transmission such as increased close contact with other people due to being in school, holidays, and staying inside during colder days. However, these nuances are beyond the scope of this dissertation and were not able to be studied by the data collected. See Figure 5.12 for a discussion about why dehumidifier use was not included in this model.

5.5.3.2. Multiple Imputation of Missing Data

The outcomes for this aim had high proportions of missing data (7.34 % for any asthma symptoms; 7.67% for any cold/ allergy symptoms), which were above 10% when combined with the missing hygrometer data (3.80%). Because of the potentially large amount of information that would have been dropped from the models, complete case analysis would have led to a large loss of precision and could bias the estimates appreciably. Beunckens, et al found that multiple-imputation based Generalized Estimating Equation (GEE) models are fairly precise and provide more accurate estimates, even when the imputation model is not perfectly specified (141). Therefore, the researcher decided to use multiple imputation methods, to impute missing values from existing data.

The researcher hypothesized that the data were missing at random and that missingness was related to covariates measured in the enrollment survey. The researcher analyzed missing data patterns using the SAS macro %missingPattern (142). Based the macro results, there was not one particular subset of participants that did not complete the surveys. Most (96.7%) of the missing outcome data were due to non-responses to the whole weekly survey, rather than non-response to one question. Six variables that had large proportions of missing data (≥85%) due to only being included in surveys for asthmatic participants; therefore, these variables were not planned for use in Aim 2 analysis. Variables with > 9% of observations missing were from somewhat sensitive questions such as the number of people supported by income, other race, and mold, roaches, and rodents in the home.

After examining univariate distributions of missing data, the researcher created two variables indicating missing outcome. Bivariate associations between the indicator variables and other covariates were examined with a Chi square or Exact test for associations. Missing asthma symptoms and missing cold/ allergy symptoms were related to missing other WHD variables, phase, school, RH levels, building occupancy, water damage, no allergic and asthma status at baseline, gender, non-Hispanic ethnicity, Caucasian race, higher education, teaching experience > 10 years, school type, building age, non-smoking status, and HVAC maintenance. Out of those strongly associated with missing outcome, the following variables were complete: phase, allergies, ever diagnosis with asthma, gender, Caucasian race, teaching experience, school type, ever smoker, and allergies to mold, dust, and pollen. The variables ethnicity, Caucasian race, education, and school had sparse cell counts (n<5) in the bivariate distributions, so the researcher chose not to explore these further for imputation modeling.

Missing data patterns between the missing outcome variables and the remainder of the associated variables were further explored using a GEE model similar to the model used for analysis, to account for clustering by participant. Building occupancy, asthma diagnosis, pollen allergy, and HVAC maintenance were strongly associated with the probability of missing data.

TABLE 5.4. FACTORS ASSOCIATED WITH RISK OF MISSING OUTCOME

		Asthma symptoms missing		Cold/ allergy symptoms missing	
Covariate	Level	N (%)	β (SE)*	N (%)	β (SE)*
Relative humidity	Low (<30%)	112 (17.81)	-0.0320 (0.0397)	115 (17.50)	-0.0139 (0.0407)
	High (>50%)	283 (44.99)	0.0473 (0.0263)	288 (43.84)	0.0457 (0.0255)
	Recommended (30-50%)	234 (37.20)	Ref.	254 (38.66)	Ref.
Building occupancy that day	Yes	423 (67.25)	-0.0217 (0.0112)	442 (67.28)	-0.0208 (0.0107)
	No	206 (32.75)	Ref.	215 (32.72)	Ref.
Water damage	Yes	461 (73.29)	0.4576 (0.4278)	482 (73.36)	0.4843 (0.4115)
	No	148 (23.53)	Ref.	155 (23.59)	Ref.
Number of rooms sharing air supply	1	387 (61.53)	Ref.	408 (62.10)	Ref.
	2	39 (6.20)	-0.0530 (0.9057)	39 (5.94)	-0.1060 (0.9003)

	3-4	42 (6.68)	-0.3601 (0.5360)	49 (7.46)	-0.3215 (0.4873)
	>6	141 (22.42)	-0.1020 (0.6486)	141 (21.46)	-0.1563 (0.6433)
Ever diagnosed with asthma	Yes	33 (5.25)	-1.5150 (0.5437)	40(6.09)	-1.3484 (0.4739)
	No	596 (94.75)	Ref.	617(93.91)	Ref.
Mold allergy	Yes	102 (16.22)	-0.4784 (0.4231)	130(19.79)	-0.2428 (0.3775)
	No	527 (83.78)	Ref.	527(80.21)	Ref.
Pollen allergy	Yes	83 (13.20)	-1.1415 (0.4013)	104(15.83)	-0.9264 (0.3744)
	No	546 (86.80)	Ref.	553(84.17)	Ref.
Dust mite allergy	Yes	122 (19.40)	-0.3197 (0.4063)	150(22.83)	-0.1375 (0.3730)
	No	507 (80.60)	Ref.	507(77.17)	Ref.
Building/ building wing age (years)	>40	21 (34.34)	0.5123 (0.4735)	216(32.88)	0.5156 (0.4742)
	31-40	103 (16.38)	0.3420 (0.5828)	110(16.74)	0.4071 (0.5612)
	11-20	149 (23.69)	-0.4771 (0.6364)	170(25.88)	-0.3079 (0.5731)
	0-10	161 (25.60)	Ref.	161(24.51)	Ref.
Ever smoker	Yes	104 (16.53)	-0.5489 (0.4420)	104(15.83)	-0.6051 (0.4352)
	No	525 (83.47)	Ref.	553(84.17)	Ref.
District	Coastal	355 (56.44)	-0.1348 (0.4325)	362(55.10)	-0.2100 (0.4114)
	Piedmont	274 (43.56)	Ref.	295(44.90)	Ref.
Frequency of HVAC maintenance	As Needed	42 (6.68)	-1.3269 (0.7080)	56(8.52)	-1.0179 (0.6209)

	Quarterly	375 (59.62)	-0.4676 (0.4812)	382(58.14)	-0.4814 (0.4700)
	Annually	212 (33.70)	Ref.	219(33.33)	Ref.
Gender	Female	498 (79.17)	-0.1813 (0.5280)	519(79.00)	-0.1757 (0.5080)
	Male	131 (20.83)	Ref.	138(21.00)	Ref.
Teaching experience (years)	>10	410 (65.18)	-0.0137 (0.5166)	424(64.54)	0.0142 (0.5128)
	4-10	122 (19.40)	-0.4624 (0.5818)	136(20.70)	-0.3560 (0.5598)
	0-3	97 (15.42)	Ref.	97(14.76)	Ref.
School type	High School	260 (41.34)	0.4052 (0.4872)	267(40.64)	0.3540 (0.4686)
	Middle School	112 (17.81)	0.1038 (0.5305)	119(18.11)	0.0696 (0.5068)
	Elementary school	257 (40.86)	Ref.	271(41.25)	Ref.
Phase	2	493 (78.38)	-0.1191 (0.4334)	514(78.23)	-0.1027 (0.4175)
	1	136 (21.62)	Ref.	143 (21.77)	Ref.

*GEE estimates with referent= non-missing outcome, clustered by classroom.

The variables of interest for analysis were all categorical or dichotomous and had an arbitrary missing pattern. Based on recommendations from the SAS technical support statistician and procedure developer, Proc MI with a fully conditional specification was the most appropriate tool available for imputation of these data in SAS V9.3 (111, 143). The imputation models for the outcomes included the all potential confounders specified in the DAGs in the previous sections, all variables correlated with the outcomes, and all variables strongly associated with the risk of missing outcome. The continuous variable, average daily indoor RH, was imputed rather than the original categorical variable for RH, using variables associated with the risk of missing exposure and covariates used in Aim 1 analysis. The imputed average daily indoor RH was then categorized into a three level variable for analysis as described in Table 5.2.

Both the original and the imputed datasets were used for the following analyses. The regression results of the 20 imputed datasets were combined and summarized. Results from the summarized imputation analyses and the original analyses were reported and compared.

5.5.3.3. Asthma and Cold/ Allergy Symptom Models

Initially, the researcher calculated the relationships between the main exposure (RH) and respiratory health outcomes (asthma and cold/ allergy symptoms). Since this was a prospective cohort study with the goal of measuring the risk of symptom occurrence among teachers, the researcher chose to use risk ratios (RR) as the measures of association. The baseline risks were 0.05 (0.03, 0.07) for having any asthma symptoms versus none and 0.23 (0.18, 0.28) for having any cold/allergy symptoms versus none.

Both bivariate and multivariate models (Equation 5.9) were fitted with GEE models to account for the data clustering within classroom over time, ordered by centered date of follow-up. Specifically, the researcher chose to fit the data to the modified Poisson regression model for correlated binary data, as described by Zou and Donner (144, 145) .

$$\log(\mu_{it}) = \hat{\beta}_0 + \hat{\beta}_n x_{it}^{(n)} \qquad \text{(Equation 5.9)}$$

where μ_{it} =average risk for event=1, x=observed exposure/covariate, n= number of covariates, t=time(days), i=individual participant.

Since outcome occurrences (event=1) closer in time had a higher correlation than outcome occurrences further apart in time, an autoregressive (AR) error correlation matrix was used to model time-dependence (135). Though the AR correlation matrix overestimated the correlation between data points (for example: estimated correlation =0.49 and actual correlation=0.1), the GEE model is fairly robust to working correlation matrix choice and the AR was still the closest fit for the pattern of correlations of within subject symptom occurrences (144). To test the robustness of the model to specification of different working correlation matrices, the researcher estimated the bivariate association between asthma symptoms and RH levels using the AR, independent, and exchangeable correlation structures. The AR structure produced the most precise and conservative estimates. The strength but not the direction of the association changed slightly between the three structures (Table 5.4).

TABLE 5.5. WORKING CORRELATION STRUCTURE COMPARISONS

Working Correlation Structures	30% RH β (SE)	50% RH β (SE)
Autoregressive	0.1023 (0.0966)	0.0665 (0.0892)
Exchangeable	0.1768 (0.2448)	0.1717 (0.1593)
Independent	0.5534 (0.2357)	0.0813 (0.2615)

Full models for multivariate analysis included all potential confounders as diagrammed in Figures 5.12-5.14 and described in section 5.5.3.1. Presence at school was included as an *a priori* effect measure modifier, since the researcher was interested in the stratified effect of presence at school on the relationship between RH and respiratory outcomes.

Backward selection of confounders was performed on the full model using three initial criteria to determine the order of variable removal. These criteria were as follows (in order of importance): variable not indicated as a confounder on the DAG, variable not in original analysis plan, and variable had a high p-value (>0.05) in the full model. Variables were ranked in order of removal according to how many criteria they met. For the non-imputed dataset, the variables were left out of the model if their removal had the following effects (in order of importance): changed the main estimate by < 5%, decreased the quasi-likelihood information criteria (QIC) and QICu (thus improving the model fit), and improved precision of the main estimate (146). For the imputed dataset, the variables were left out of the model if their removal produced <5% change in estimate and improved precision, since the procedure used to combine the imputation results could not produce a summary QIC.

All models were run with no lag time between the exposure and outcome. The final models for the imputed data were also run with 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 average daily relative humidity observation from two days before the outcome observation (day=t-2).

6. MATERIALS AND METHODS: STUDY POPULATION CHARACTERISTICS

6.1. COMPARISON OF PARTICIPATING SCHOOL DISTRICTS

Table 6.1 illustrates the characteristics of the participating school districts including district resources and demographics of the teachers and student body. Chapel Hill-Carrboro City Schools, located in the Piedmont, is one of the wealthiest school districts in the state, with a higher average number of full-time teachers per school and higher teacher salary supplements than New Hanover County Schools. New Hanover County Schools, located in the southeastern coastal region of the state, has a larger number of schools and a moderate resource base, with a higher percent of children living below the poverty level compared to Chapel Hill-Carrboro City Schools and lower per pupil expenditures (116, 133).

TABLE 6.1: CHARACTERISTICS OF PARTICIPATING SCHOOL DISTRICTS, 2011(116, 133)(DEPARTMENT OF PUBLIC INSTRUCTION 2011; UNITED STATES CENSUS BUREAU 2011)

School District	Number of Schools	Average Number of Teachers per School	Average Local Salary Supplements for Teachers	Total Per Pupil Expenditure (Including Child Nutrition)	Percent (%) of children (< 18 years) below the poverty level*
Chapel Hill-Carrboro City	18	50	$5,922	$ 10,605	Chapel Hill town 12.6 (±3.1) Carrboro town 15.0 (±7.8)
New Hanover County	41	40	$3,449	$ 8,777	20.0 (±2.1)

*5-year average, based on 2010 U.S. Census Estimates, American Community Survey (116)

6.2. TEACHER PARTICIPATION

Of the 569 full-time classroom teachers invited to participate, 122 (21%) consented, completed the baseline questionnaire (enrollment survey), and were found to be eligible. Phase 1 and Phase 2 had 17% and 24% participation, respectively. In addition to the higher participation rate in Phase 2 relative to Phase 1, the absolute number of Phase 2 participants was higher since more schools were recruited during Phase 2 (6 schools) than Phase 1 (4 schools).

Once participants were consented, the majority completed their online enrollment surveys (Phase 1 =95% completed; Phase 2= 96% completed) (Figures 6.1 and 6.2). Ten participants who signed consent forms were later dropped, including 4 participants who did not complete the enrollment survey and 6 participants who did not meet the eligibility criteria of being full-time, classroom teachers. Ineligible participants included a teacher's assistant, a vice principal, a school counselor, an in-school suspension teacher, and a school nurse. Another ineligible participant worked part-time at two schools. Therefore, the teacher was full-time for payroll purposes but was considered part-time at the participating school for the purposes of reporting to the Department of Public Instruction. Because teachers listed as full-time under Department of Public Instruction rules were our base population, this difference rendered the participant ineligible. Participants were informed of their ineligibility if it was discovered by the researcher before follow-up was complete.

FIGURE 6.1. PHASE 1: PARTICIPATION FLOWCHART

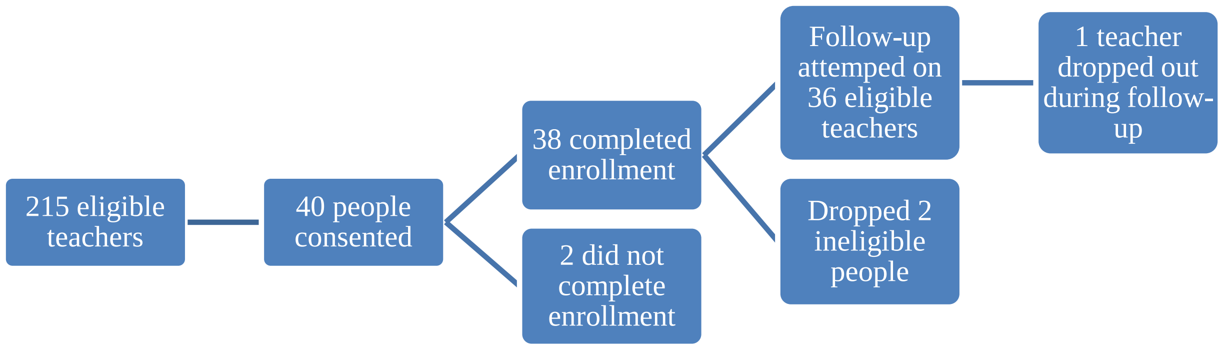
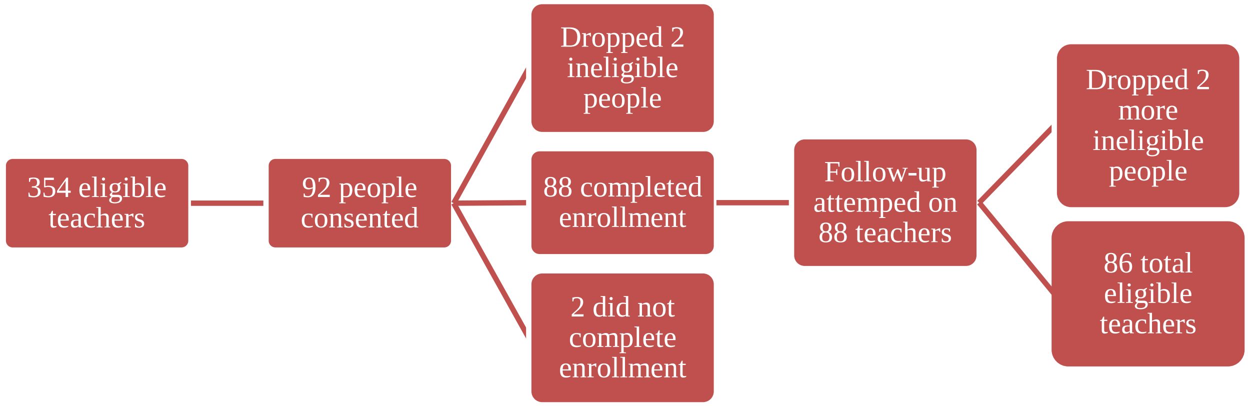


FIGURE 6.2. PHASE 2: PARTICIPATION FLOWCHART



6.3. RETENTION

A participant was considered retained if he or she stayed until the end of follow-up (i.e. completed the final survey). The intended follow-up time for Phase 1 was eight weeks, while the intended follow-up time for Phase 2 was twelve weeks. The shortened follow-up periods listed in Table 6.2 were due to left-truncation, where an entire school or individual participant was enrolled later than expected due to scheduling conflicts, delays in recruitment, or illness. One Phase 2 participant's follow-up time was abbreviated (right-truncated to 10 weeks) due to a scheduled job transfer to another non-participating school.

The proportion of teachers retained was 85% overall (Table 6.2). Retention was slightly higher in Phase 1 than Phase 2 of the study. Retention was similar when comparing the 8 and 12 weeks of standard follow-up time between the two phases.

The researcher considered the teachers as having completed 100% of their weekly health diaries if they completed one survey per week of follow-up, regardless of the dates of survey submissions. Almost all study participants (89.3%) completed at least 80% of their surveys, and three-quarters of all participants completed all of their surveys (Table 6.2). Survey completion was higher for Phase 2 than Phase 1; however, survey completion did not vary inversely with follow-up time, as previously expected.

TABLE 6.2. PARTICIPANT RETENTION BY LENGTH OF FOLLOW-UP

Study Phase	Follow-up Length (Weeks)	Number of Participants Followed (N)	Percent (%) of Participants Retained	Percent (%) of Participants Who Completed 100% of Surveys	Percent (%) of Participants Who Completed ≤80% of Surveys
Phase 1	All	36	86.1	69.4	88.9
	4	1	100	100	100
	6	23	78.3	65.2	82.6
	7	3	100	100	100
	8	9	88.9	66.7	100
Phase 2	All	86	84.9	77.9	89.5
	9	12	83.3	66.7	83.3
	10	2	50.0	50.0	100
	12	72	88.6	84.3	95.7
Both	All (4-12)	122	85.2	75.4	89.3

During Phase 2, two participants and one administrative contact person were no longer working at their respective schools by the end of the 12 week follow-up period. By the next school year, there was additional turnover of two superintendents, an administrative contact person, and a maintenance contact person, suggesting that school employee populations may present special challenges with respect to follow-up due to high employee turnover rates.

6.4. CHARACTERISTICS OF PARTICIPANTS

6.4.1. Demographics

Table 6.3 presents the demographics of eligible participants by study phase. All demographic data presented below were self-reported by participants during the enrollment survey, except for participants' ages which was calculated by the researcher from date of birth reported on the contact information sheet. The average age of participants was 40.8 (range= 24-65). The average age was younger for Phase 2 participants compared to Phase 1 participants.

Most study participants were female, which was expected given the demographics of the teacher base population (133). A higher percentage of males participated in Phase 2 (18.6%) compared to Phase 1 (8.3%) (Table 6.3).

Eligible participants completed all demographic questions except for self-identified Hispanic ethnicity. Ethnicity was missing for only <5% of the total participants; however, it was missing for 11.1% of Phase 1 participants. The majority (95.1%) of participants self-identified as white or Caucasian, with a similar distribution of self-reported race between Phase 1, Phase 2, and the study population overall. Four out of five participants who indicated "Other Race" also identified as white or Caucasian. The explanations written in for "Other Race" included "Hispanic" and "Race is a social construct."

More than half of the participants reported the bachelor's degree as their highest level of educational attainment, with a higher percentage of terminal bachelor's degrees among Phase 1 compared to Phase 2 participants. A bachelor's degree is now the minimum degree required to attain professional licensure within the North Carolina public school system (http://www.dpi.state.nc.us/licensure/beginning/). Phase 2 participants had a higher percentage of master's degrees, and only Phase 2 participants had other advanced degrees.

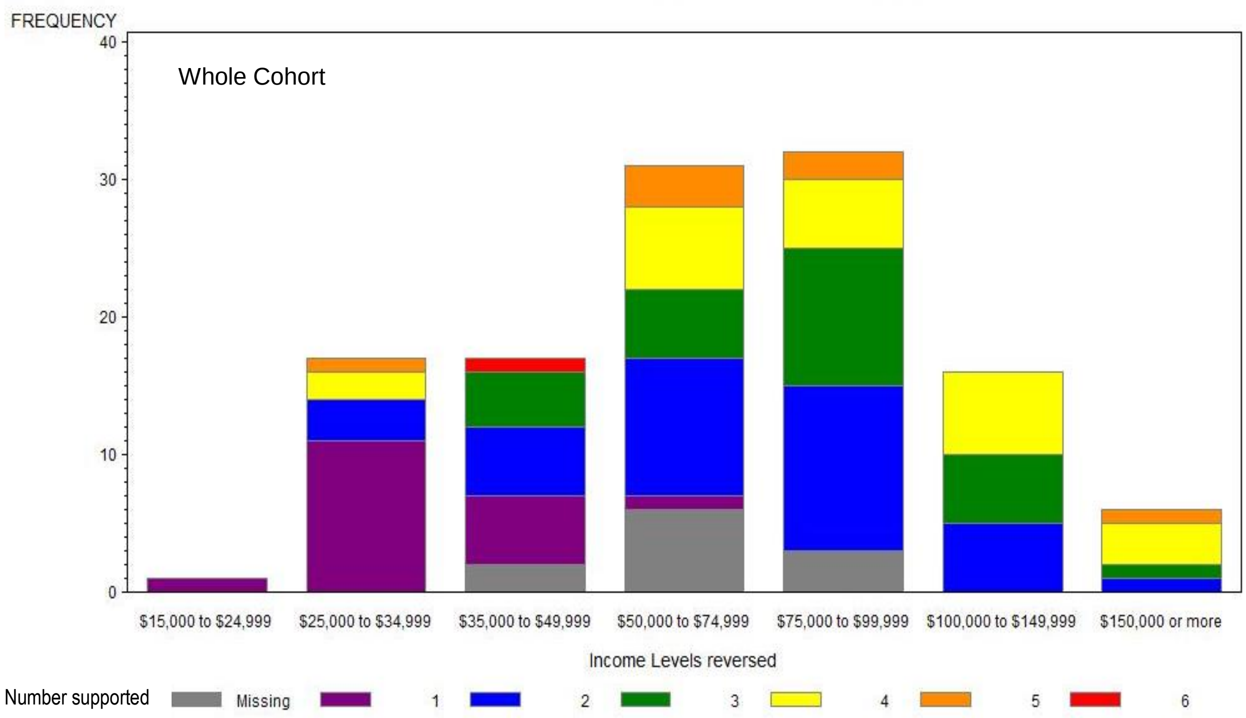
TABLE 6.3. DEMOGRAPHICS OF ELIGIBLE PARTICIPANTS *

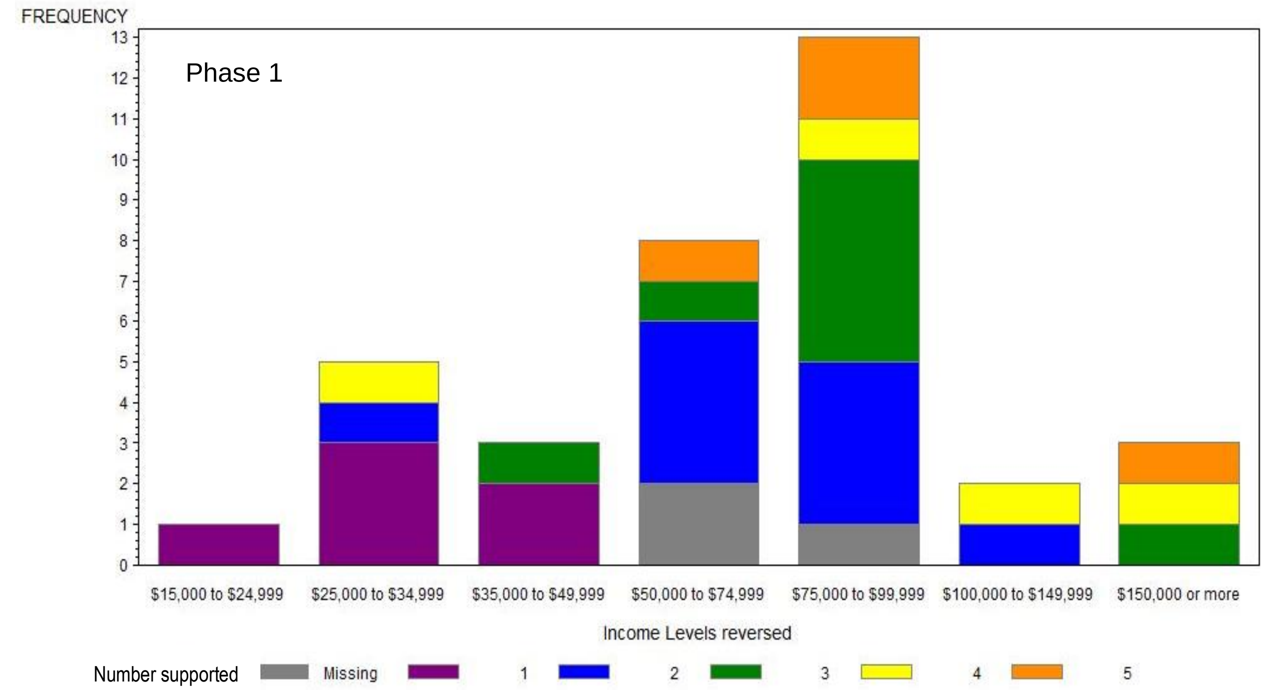
Variable	Value	Fall Phase 1	Spring Phase 2	Total
		Mean (SD)	Mean (SD)	Mean (SD)
Age at Enrollment		42.7 (12.2)	40.0 (11.9)	40.8 (12.0)
		N (%)	N (%)	N (%)
Sex	Male	3 (8.3)	16 (18.6)	19
	Female	33 (91.7)	70 (81.4)	103
	Missing	0 (0)	0 (0)	0 (0)
Race**	Black	2 (5.6)	3 (3.5)	5 (4.1)
	White	33 (91.7)	83 (96.5)	116 (95.1)
	Other	1 (2.8)	4 (4.7)	5 (4.1)
	Missing	0 (0)	0 (0)	0 (0)
Ethnicity	Hispanic	1 (2.8)	1 (1.2)	2 (1.6)
	Non-Hispanic	31 (86.1)	83 (96.5)	114 (93.4)
	Missing	4 (11.1)	2 (2.3)	6 (4.9)
Education Level	Bachelor’s	22 (61.1)	41 (47.7)	63 (51.6)
	Master's	14 (38.9)	42 (48.8)	56 (45.9)
	Other Advanced Degree	0 (0)	3 (3.5)	3 (2.5)
	Missing	0 (0)	0 (0)	0 (0)
Total	Population Size	36 (29.5)	86 (70.5)	122 (100)

* Eligible participants include those who completed the enrollment survey and were full-time teachers at enrollment. ** Total percent does not add up to 100 because some people chose more than one category for race.

Figure 6.3 illustrates the distribution of participants’ reported annual household income levels, overall and by phase. Colored bars indicate the number of people supported by this income. The income distribution was normal for Phase 2 (median=$50,000 to $74,999, skew= 0.003) and for the whole cohort (median=$50,000 to $74,999, skew=0.08). However, the Phase 1 distribution was left-skewed (median=$75,000 to $99,999, skew=0.25). Income was missing for two participants. Number of people supported was missing for 11 middle-income participants ($35,000 to $99,999). The number of people supported generally increased with household income level, though the average household income level was lower for households with five or six people than in households with only four people to support (Figure 6.4). A few individuals with household incomes of $25,000 to $34,999 stated that they support four or more dependents, putting them near or below the poverty guideline at the time of the survey ($22,350 for four people and $26,170 for five people) (147).

FIGURE 6.3. PARTICIPANTS' HOUSEHOLD INCOME AND NUMBER SUPPORTED




FREQUENCY
Phase 1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
$15,000 to $24,999
$25,000 to $34,999
$35,000 to $49,999
$50,000 to $74,999
$75,000 to $99,999
$100,000 to $149,999
$150,000 or more
Income Levels reversed
Number supported
Missing
1
2
3
4
5

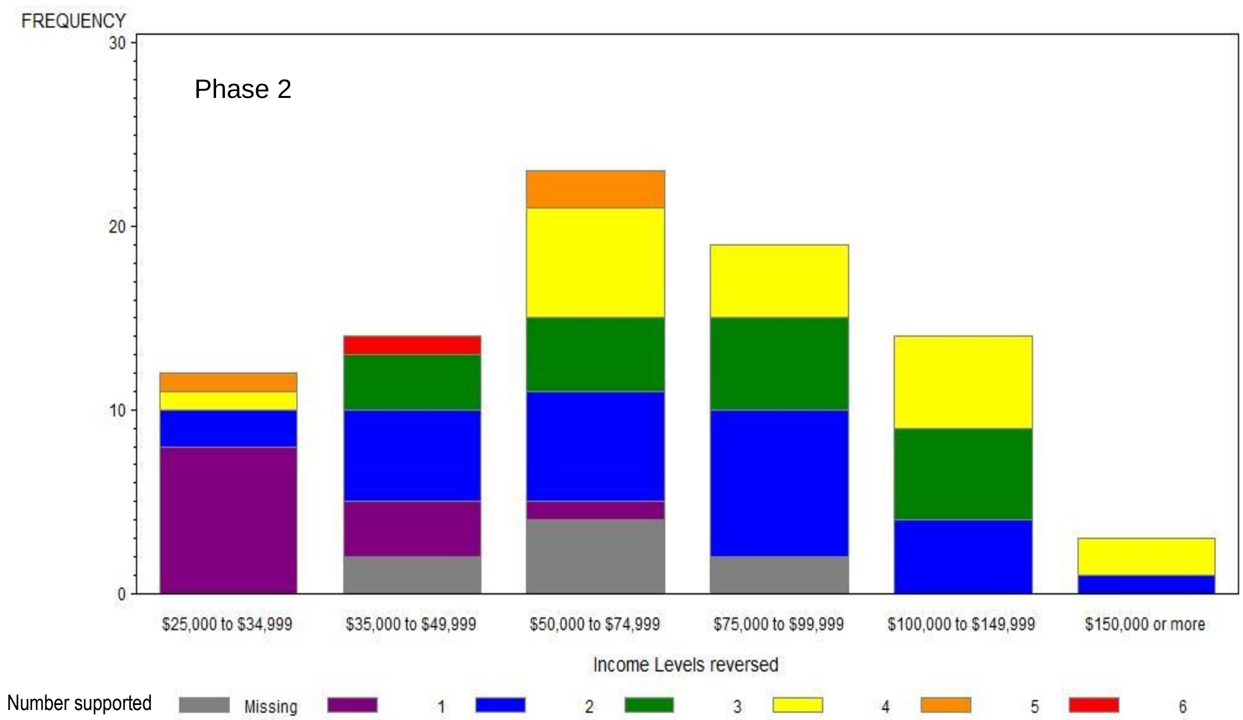
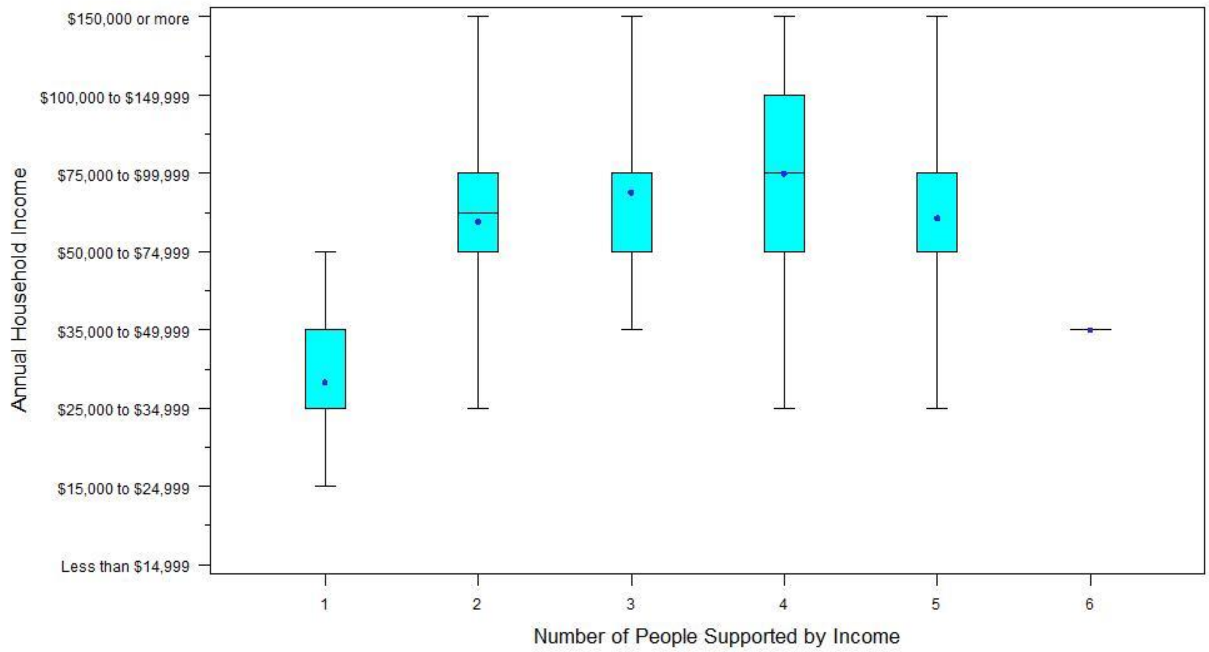

FREQUENCY
Phase 2
0
10
20
30
$25,000 to $34,999
$35,000 to $49,999
$50,000 to $74,999
$75,000 to $99,999
$100,000 to $149,999
$150,000 or more
Income Levels reversed
Number supported
Missing
1
2
3
4
5
6

FIGURE 6.4. ASSOCIATION BETWEEN NUMBER SUPPORTED AND INCOME



6.4.2. Baseline Medical and Exposure History

There were no data missing for the question determining asthma status of participants (Table 6.4). The overall percentage of participants with asthma (14.8%) was higher than the proportion of adult NC residents with asthma in 2010 [12.6% (11.6-13.7)]) (77). However, Phase 1 participants had 1.14 (0.94, 1.37) times the prevalence of asthma diagnosis at baseline among Phase 2 participants. Of the 18 participants with diagnosed asthma at baseline, 11 had current asthma (defined as having asthma attack within the past 12 months). Most (63%) of those with current asthma were Phase 1 participants.

Around 47% of participants were diagnosed with asthma during adulthood (18 or older). Among Phase 1 participants with asthma, 62.5% were diagnosed as adults. However, only 33.3%

of Phase 2 participants with asthma were diagnosed as adults. One Phase 2 participant was missing age at asthma diagnosis.

Over half of participants stated that they have allergies (Table 6.4). Sensitivities to mold/ mildew, dust/ dust mites, and pollen (spring or fall) were the most commonly reported allergy types, with one-quarter to one-third of participants having a reaction to at least one of these allergens. As with asthma, Phase 1 participants had 1.20 (0.77, 1.86) times the prevalence of allergies among Phase 2 participants.

Most participants answered that they had been exposed to at least one potential irritant at home (Table 6.4). Data on household roaches, rodents, and mold were missing for approximately 30% of participants. None of the participants categorized as never smokers reported home exposure to secondhand smoke. Information on smoke in the house was missing for one participant (former smoker).

The majority of the study cohort reported never smoking (Table 6.4). Only 3 out of 33 ever smokers classified themselves as current smokers. Two current and one former smoker were the only ones who reported smoke inside of their houses.

TABLE 6.4. MEDICAL AND EXPOSURE HISTORY OF PARTICIPANTS (N=122)*

Variable	Value	Fall Phase 1	Spring Phase 2	Total
		Mean (SD)	Mean (SD)	Mean (SD)
Years Worked in Current School Building		8.5 (7.9)	4.9 (4.7)	6.0 (6.0)
		N (%)	N (%)	N (%)
Diagnosed Asthma	Yes	8 (22.2)	10 (11.6)	18 (14.8)
	No	28 (77.8)	76 (88.4)	104 (85.3)
	Missing	0 (0)	0 (0)	0 (0)
Allergies	Yes	21 (58.3)	43 (50.0)	64 (52.5)
**Types	Mold	11 (30.6)	19 (22.1)	30 (24.6)
	Dust mites/ dust	11 (30.6)	23 (26.7)	34 (27.9)
	Cockroaches	4 (11.1)	2 (2.3)	6 (4.9)
	Food	5 (13.9)	5 (5.8)	10 (8.2)
	Pollen (Spring)	12 (33.3)	28 (32.6)	40 (32.8)
	Pollen (Fall)	13 (36.1)	26 (30.2)	39 (32.0)
	All pollen***	13 (36.1)	29 (33.7)	42 (34.4)
	Cats	8 (22.2)	14 (16.3)	22 (18.0)
	Dogs	3 (8.3)	6 (7.0)	9 (7.4)
	Other	10 (27.8)	14 (16.3)	24 (19.7)
	No	11 (30.6)	29 (33.7)	58 (47.5)
	Missing	0 (0)	0 (0)	0 (0)
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)
	Missing	0 (0)	0 (0)	0 (0)
Smoke in House	Yes	0 (0)	3 (3.5)	3 (2.5)
	No	36 (100.0)	82 (95.4)	118 (96.7)
	Missing	0 (0)	1 (1.2)	1 (0.8)
Any Home Exposures	Yes	36 (100.0)	82 (95.4)	118 (96.7)
	No	0 (0)	4 (4.7)	4 (3.3)
	Missing	0 (0)	0 (0)	0 (0)

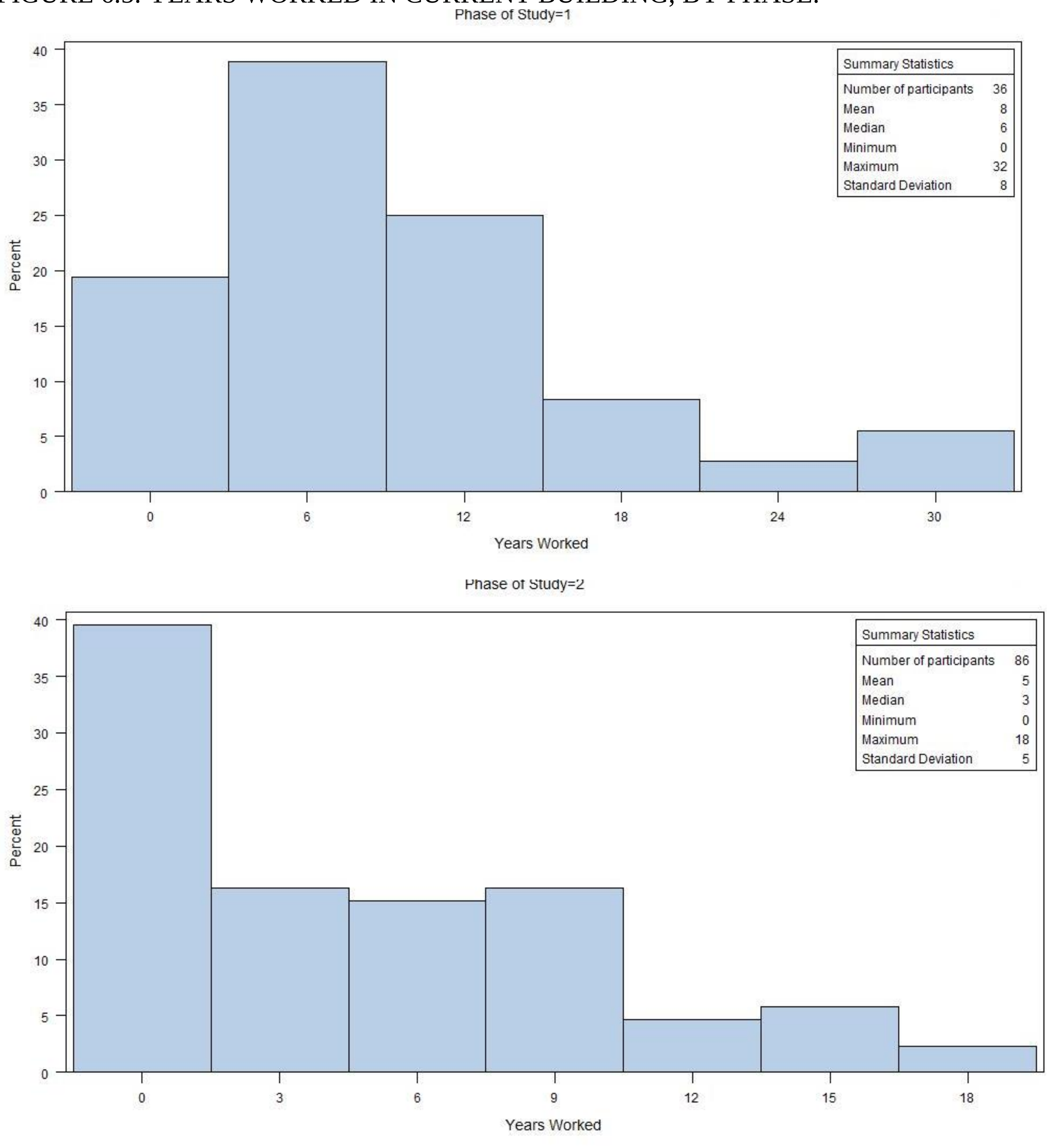
* Eligible participants include those who completed the enrollment survey and were full-time teachers at enrollment. ** Total % does not add up to 100 because some people chose more than one category for race. *** All pollen includes answers written in by participants under "Other allergens" that fit into the category of pollen allergies.

Most teachers who participated in our study worked for less than 10 years in their current school buildings, suggesting a brief history of exposure in this particular workplace under study (Figure 6.5). On average, participants worked in the same building for 6 years. Phase 1 participants worked for 8.5 years on average in the same building; whereas Phase 2 participants worked only for an average of 4.9 years.

Half of participating schools (N=5) consisted of only one building. Three school complexes contained multiple permanent structures; whereas, the two other school complexes utilized temporary trailers to supplement the main school building. Years worked in the current building was highly correlated with years worked at the current school (r^2=0.93), suggesting that classroom assignments stayed the same for much of participants' employment.

Surprisingly, the number of years of teaching experience is not well correlated with the number of years worked in the current building (r^2=0.35). Over half of the participants have more than 10 years of teaching experience, overall and by phases, suggesting that transition between schools was common during a teachers' tenure (Table 6.3).

FIGURE 6.5. YEARS WORKED IN CURRENT BUILDING, BY PHASE.



6.4.3. Comparison of Study Participants to Base Population

Teaching tenure among both Phase 1 and Phase 2 participants overall was comparable to tenure of the eligible population (all full-time, classroom teachers at participating schools) (Table 6.5). However, participant experience differed slightly from the base population by school type. Among Phase 1 participants, there were higher proportions of elementary and middle school teachers in the highest and lowest tenure categories, compared to the eligible population. Among Phase 2 participants, the majority of elementary and high school teachers had >3 years of teaching experience. Elementary school teachers who were Phase 2 participants had more experience compared to the base population. Middle school teacher participants were typically in either extreme of the experience categories, compared to the base population of middle school teachers who were more evenly distributed with respect to tenure.

For Table 6.5, participants who completed any higher degree after a bachelor's degree were classified as having an advanced degree. A higher proportion of both Phase 1 and Phase 2 study participants had advanced degrees compared to the eligible population; however, this difference is especially pronounced between Phase 2 participants and the eligible population. For Phase 1, this difference was greatest among middle school teacher participants. For Phase 2, this difference was the most notable among high school teachers (Table 6.5).

Demographic information on race and gender reported by the NC Department of Public Instruction was aggregated to the district level. Therefore, these demographics could not be stratified further by school (Table 6.6) (133).

Overall, a higher proportion of females enrolled in the study population compared to the proportion of females in the base population (Table 6.6). An especially high proportion of females participated from New Hanover County School District [90.9% compared to 73.3% female among Chapel Hill-Carrboro City Schools participants]. In addition, a higher percentage of participants self-identified as white/ Caucasian in both districts compared to the base population. Among Chapel Hill-Carrboro City Schools participants, teachers who self-identified as black were less likely to participate in our study. Because of the lack of school-specific demographic data, these results are difficult to interpret.

Though New Hanover County Schools had over twice the teacher population size as Chapel Hill-Carrboro City Schools and had more than twice the number of schools participating in the study, New Hanover County Schools had only 1.7 times the number of individuals participating from Chapel Hill-Carrboro City Schools (Table 6.6). Possible reasons for high participation at Chapel Hill-Carrboro City Schools included more support from the school administration or identification with the researcher as a member of the Chapel Hill community. Due to the proximity to UNC, Chapel Hill-Carrboro City Schools were also used to having student researchers from both public health and other departments, and some teachers may have been graduates of the university. Lastly, all three Chapel Hill-Carrboro City Schools buildings had previous IAQ issues; whereas, this was not true for all New Hanover County Schools buildings. Each of these factors may have incentivized more teachers to participate in Chapel Hill-Carrboro City Schools than New Hanover County Schools.

The Department of Public Instruction did not report ages of teachers. Attempting to supplement the available statistics with school-specific data, I requested that Phase 1 school principals send aggregate data about the age, gender, and racial distribution of their teacher base. However, some school principals did not feel comfortable reporting employee demographics. Furthermore, the information reported by one school did not match a sample of data attained from the district's human resources department. Thus, no attempt was made to collect this information from principals of any Phase 2 schools.

TABLE 6.5. STUDY PARTICIPANTS COMPARED TO ALL ELIGIBLE TEACHERS, BY PHASE AND SCHOOL TYPE.(133)

		Population Eligible					Participants				
			Degree	Years of Teaching Experience				Degree	Years of Teaching Experience		
			>Bachelor's	0-3	4-10	10+		>Bachelor's	0-3	4-10	10+
Phase	School Type*	Total (N)	Percent (%)	Percent (%)	Percent (%)	Percent (%)	Total (N)	Percent (%)	Percent (%)	Percent (%)	Percent (%)
1	E	74	37.8	13.4	36.6	50.0	18	38.9	16.7	27.8	55.6
	M	44	25.0	2.0	39.0	59.0	9	55.6	11.1	22.2	66.7
	H	97	28.0	16.0	24.0	61.0	9	22.2	11.1	44.4	44.4
	Total	215	30.8	12.2	31.4	56.8	36	38.9	13.9	30.6	55.6
2	E	117	38.4	13.1	34.3	53.6	43	41.9	7.0	39.5	53.5
	M	41	27.0	34.0	32.0	37.0	16	43.8	37.5	25.0	37.5
	H	196	38.2	9.5	30.9	60.5	27	74.1	11.1	33.3	55.6
	Total	354	37.0	13.6	32.2	55.5	86	52.3	14.0	34.9	51.2
Both	Total	569	34.6	13.1	31.9	56.0	122	48.4	13.9	33.6	52.5

*E=Elementary, M=Middle, H=High School

TABLE 6.6. COMPARISON OF STUDY PARTICIPANTS TO THE TARGET POPULATION, BY SCHOOL DISTRICT.(133)

	All Teachers*					Participants				
		Gender	Race				Gender	Race		
		Female	White	Black	Other		Female	White	Black	Other
School District	Total (N)	Percent (%)	Percent (%)	Percent (%)	Percent (%)	Total (N)	Percent (%)	Percent (%)	Percent (%)	Percent (%)
New Hanover County	1598	78.7	91.6	6.2	2.3	77	90.9	93.5	5.2	3.9
Chapel Hill-Carrboro City Schools	750	76.9	78.5	16.3	5.2	45	73.3	97.8	2.2	4.4
Grand Total	2348	78.2	87.4	9.4	3.2	122	84.4	95.1	4.1	4.1

*This group includes all teachers, not just teachers employed at participating schools. Teachers employed at non-participating schools were not eligible to participate in our study.

6.4.4. Participant Characteristics Related to Aim 2 Analysis

6.4.4.1. Participant Time in Classrooms

At enrollment, participants were asked about whether or not they spend more than 30 minutes per day in multiple classrooms. When possible, the researcher placed hygrometers in all listed classrooms. However, because participants were not asked to write their weekly schedules prospectively, RH data were limited to only the main classroom for analysis. A higher proportion of participants in Phase 1 compared to Phase 2 spent their weeks in multiple classrooms (Table 6.7). Overall, participants spent an average of 40 hours per week in their first listed room.

TABLE 6.7. PARTICIPANT LOCATION AND TIME, BY SCHOOL TYPE AND PHASE*

	Phase 1				Phase 2			
	Number of rooms listed				Number of rooms listed			
School Type	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
Elementary	8	7	1	2	30	7	6	0
Middle	0	5	4	0	5	7	4	0
High**	1	4	0	3	19	6	2	0
Participant Total	9	16	5	5	54	20	12	0
Order listed	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Number of hours spent per week, μ(σ)**	38.8 (11.3)	5.4 (5.4)	5.8 (4.0)	9.6 (4.6)	39.7 (8.4)	6.3 (7.4)	3.6 (1.8)	0

*Participants were asked to list rooms in which they spent > 30 minutes in an average day
**Missing, n=1 in Phase 1, high school; n=5 in Phase 2.

7. RESULTS: PAPER 1.THE EFFECTS OF SCHOOL BUILDING FACTORS ON CLASSROOM RELATIVE HUMIDITY CONTROL: LESSONS FROM THE "FREE TO BREATHE, FREE TO TEACH" STUDY

7.1. INTRODUCTION

The warm, humid climate of the southeastern United States presents challenges to maintaining indoor air quality in school buildings. In the past decade, a statewide, environmental health survey revealed evidence of flooding (35%), visible mold (49%), roaches (77.5%), rodents (73%), and moldy odors (73%) in North Carolina public schools (110). These findings were clearly suggestive of excessive indoor humidity. Such reports are concerning, because studies of populations living in homes with excessive dampness suggest that these environments are hazardous to the respiratory health of occupants (3, 4).

To date, school studies related to indoor dampness have been largely based on visual inspections and mold tests. Relative humidity (RH), which measures the amount of water that air can hold at a given temperature without forming condensation, can be recorded using simple, low cost technology (27). The current study uses RH as a direct, quantitative measure of dampness and identifies the structural conditions that are related to RH control in schools.

Outdoor humidity and temperature, which vary by season and geography, affect indoor humidity and temperature by moving air in through openings in the building envelope via low pressure caused by warm air moving upward, also known as the "stack effect" (60, 148). While outdoor humidity and temperature are outside of the control of school facilities maintenance personnel, there are several building-related factors that may influence indoor relative humidity and can be addressed by schools. Building envelope permeability, the quality and frequency of maintenance, and the type and quality of insulation and air seals are among these (64). During periods of extreme temperatures with high humidity, condensation can form on poorly insulated surfaces due to the temperature differential between outdoor and indoor air (65). Another structural factor which may affect classroom humidity is the operation, maintenance, and choice of heating, ventilating, and air conditioning (HVAC) systems. Air conditioning systems in most schools are not designed specifically to control humidity, but some systems dehumidify as a result of removing moisture from the air during the cooling process (61, 62). School buildings in the Southeast are typically temperature controlled all through the year, with a "cooling season" in the warmer months and a "heating season" during the colder months. However, mild temperatures between seasons can lead to transition periods with infrequent HVAC cycling, allowing indoor air to become stagnant and retain moisture.

Ideally, the United States Environmental Protection Agency's (US EPA) "IAQ Tools for Schools" recommendations suggest that schools should keep indoor RH levels between 30-50% to gain better control of mold, dust mites, and pests (51). However, in North Carolina (NC), the responsibility for maintaining school facilities falls on the county, whose tax base or community socioeconomic status may influence schools' abilities to meet EPA standards for humidity control (67). In addition, resource-poor schools are often located in areas at risk for flooding and may delay remediation of water damage from flooding, leaks, spills, and/ or improper drainage due to the high cost of repair (27, 66).

The aim of this research was to identify factors associated with indoor air quality problems related to poorly controlled humidity in schools. We examine the association between classroom relative humidity control (30-50%) and structural factors such as school building age, mechanical ventilation and maintenance practices, and previous water damage.

7.2. MATERIALS AND METHODS

This research was part of a longitudinal cohort study of the health effects of indoor air quality factors on teachers. School district maintenance personnel in two NC school districts recruited principals from 10 public schools, elementary through high school, to allow their employees to participate in this study. Within these schools, the researcher invited all full-time teachers to have their classrooms inspected and monitored for temperature and RH, while they completed weekly health diaries for up to 12 weeks.

At the start of follow-up, a team of trained individuals inspected 233 rooms (including classrooms, common areas, and offices) according to the EPA's IAQ Tools for Schools Walkthrough Inspection procedures (51). Portable monitors recorded carbon dioxide, carbon monoxide, RH, and temperature. During these inspections, potential asthma triggers were noted using a modified Walkthrough Inspection Checklist. Water damage was assessed based on signs of current or recent damage such as rust, mold, or water spots. For analysis, a composite variable was created defining water damage as any leaks, history of flooding, or visible signs of moisture/ water damage found in the classroom during the inspection.

During follow-up, Extech data logging hygrometers recorded temperature and RH in 134 classrooms at 15 minute intervals. Hygrometers were checked for accuracy and precision with numerous tests before and during data collection. Indoor classroom RH observations were summarized as daily means. The outcome, daily mean RH, was categorized as below (<30%), above (>50%), or within the recommended RH level (30-50%), according to the EPA's recommendations for indoor RH in schools (51).

After follow-up was completed, the researcher surveyed a building maintenance expert from each school district to collect information about the type and operation of heating, ventilation, and air conditioning (HVAC) systems in each school building, building wing, and portable classroom occupied by study participants. Presence of programmed setbacks were noted for each school building and defined by whether or not a building had a different set point for unoccupied vs. occupied times. Programmed setbacks occur when building ventilation rates are reduced during unoccupied hours by changing the temperature set point on the thermostat, to conserve energy. Reducing the airflow into occupied rooms may raise the RH, due to a build-up of exhaled water vapors (68).

Building occupancy was determined based on the published school schedule for the 2010-2011 school year. Schools were considered occupied during each weekday, except on scheduled holidays, from one hour before the school day began to one hour after school ended (i.e. 7am-4pm in a school scheduled to start at 8am and end at 3pm). For each classroom, daily RH was stratified by building occupancy and averaged separately for occupied vs. unoccupied times to test differences in estimates after stratification by occupancy.

Heating and cooling days were defined using daily average outdoor temperatures that were estimated to(138)(Brager and de Dear 2001) produce indoor temperatures within 80% of the Adaptive Comfort Standards created by Brager, et al. for a naturally ventilated building (138). These outdoor temperatures were used as guides for when heating and cooling would be requested in mechanically ventilated buildings as follows: heating days= less than 15^{o}C, transition days= 15-23^{o}C, cooling days= more than 23 ^{o}C. The NC State Climate Office provided outdoor RH and temperature averaged daily from October 20, 2010 to June 14, 2011 (114).

7.2.1. Statistical Methods

The hygrometer data consisted of 852,519 RH measurements. These were initially summarized into 9066 values representing the average daily RH in the 134 study classrooms over the study period. Letting *i* denote classroom, and *t* denote day, the outcome variable Y_{it} is a variable denoting the average RH in classroom *i* during day *t*. We coded Y_{it} with a value of "3" if the average daily RH for classroom *i* on day *t* was >50%, a value of "2" if the average daily RH for classroom *i* on day *t* was <30%, and a value "1" if the average daily RH was within the recommended RH (30-50%). Comparisons were made between nominal categories 3 versus 1 and 2 versus 1.

The SURVEYLOGISTIC procedure (SAS software, Version 9.3) was used to estimate generalized logits (g-logit link, multinomial distribution) for a nominal polytomous outcome Y_{it} defined above (*Equation 1*), accounting for repeated measures by classroom using the Taylor series method for variance estimation. Multivariate models were fit with potential confounders chosen *a priori*.

$$\log\left[\frac{\Pr(Y_{it}=g|x)}{\Pr(Y_{it}=1|x)}\right]= \hat{\beta}_{0g}+\hat{\beta}_{ng}x_{nit} \qquad (\textit{Equation 1})$$

where g= outcomes 2 or 3; x=observed exposure data, n=number of covariates, t=time(days), i=individual classroom

Since geographic location was an important factor known to influence outdoor RH and school district funding influences maintenance, school district was included in the model as a potential confounder for the relationship between building age and relative humidity. However, district names were changed to protect the privacy of the participating schools. The Piedmont district contained one city and three participating schools. The Coastal district contained two cities and seven participating schools.

The effect of water damage was adjusted for cooling mechanism, outdoor RH, and building age. Building age may have affected the (unmeasured) age of the HVAC equipment in the building and so will be used as the proxy for unmeasured HVAC age. The effects of frequency of HVAC system maintenance and cooling mechanism were also adjusted for building age, for this reason. Depending on its age and design, some cooling equipment is more prone to leaking than others and thus may be more likely to cause water damage. Also, the effect of cooling mechanism was adjusted for heating/cooling season since the cooling mechanism may not be used during the heating system unless it is used for dehumidification through system reheat. The effect of having an economizer on indoor RH was adjusted for dehumidification of fresh air upon intake, which also blocks potential confounding by outdoor RH.

7.3. RESULTS

Out of 9066 classroom-days monitored, 5905 classroom-days (65%) were on days with scheduled building occupancy and 22 classroom-days (0.24%) were missing RH data. Indoor daily RH had a bimodal distribution with higher means during cooling (μ=51.9%, σ=10.2) and transition days (μ=48.7%, σ=8.8) than heating days (μ=33.0%, σ=9.0). Classrooms had a higher risk of low indoor RH (<30%) vs. controlled RH (30-50%) during the autumn and winter compared to the spring. Within schools, fluctuations in indoor RH most closely followed daily trends in outdoor temperature, whereas indoor temperature stayed fairly constant over time.

Most schools were not able to maintain recommended RH levels (30-50%) in monitored classrooms for more than half of the follow-up period. One school had poor humidity control throughout the study period. Among Phase 1 schools, a low percentage of classroom-days in December had RH within the recommended levels; however, a high percentage of classroom-days in November had recommended RH. The highest proportion of classroom-days with recommended RH occurred during the transitional period.

The odds of high indoor RH increased as outdoor humidity increased. Table 7.1 presents a full comparison of indoor and outdoor temperature and RH between school districts. High indoor RH was more likely in the Piedmont than the Coastal schools, which had a higher average outdoor RH in general. In addition, high indoor RH was more likely in very new schools (0-10 years of age) than in older schools.

Building-related factors associated with an increased odds of high classroom RH (>50%) included having less frequently scheduled HVAC maintenance and having programmed thermostat setbacks compared to no programmed setbacks (Table 7.2). Finally, the presence of an economizer in the HVAC system was associated with higher odds [$OR_{economizer}$=3.07 (2.04, 4.63)] of having high RH, after controlling for the effect of dehumidifying the fresh air upon intake (Table 7.2). However, water damage in the classroom was not associated with high average daily RH.

The odds of low RH decreased as outdoor humidity increased. In addition, low RH was more likely in the Piedmont schools than the Coastal schools, and was more likely in very new schools (0-10 years of age) and very old schools (40+ years of age) than in other schools. Having the direct-expansion split system compared to the chilled water cooling mechanism was associated with an increased odds of low (>30%) classroom RH (Table 7.3).

After stratification by building occupancy, the estimates for the associations between building-related factors and high and low vs. recommended daily RH were similar in direction and magnitude to the un-stratified estimates shown in Tables 7.2 and 7.3. Estimates for unoccupied times were almost identical to un-stratified estimates; however, estimates for occupied times were generally further from the null and less precise. For example, the association between high RH and programmed setbacks was stronger for occupied [$OR_{setbacks, occ}$= 3.48 (1.89, 6.38)] compared to unoccupied [$OR_{setbacks, unocc}$= 2.79 (1.77, 4.40)] periods of classroom use.

7.4. DISCUSSION

Classrooms in buildings that were between 11 to 40 years old had a higher risk of having RH < 30% compared to younger buildings. Building age was associated with cooling mechanism, which may overcompensate for outdoor RH during this time period. There was no standard for indoor RH at the lower end of the thermal comfort range in the 2004 ASHRAE guidelines (149). Therefore, an HVAC system installed at this time may have been designed to dehumidify the school building as much as possible without consideration of the possible health effects of humidity below 30%. Older HVAC systems may not have had the ability to dehumidify the air as efficiently as newer systems.

Compared to classrooms with quarterly HVAC maintenance, classrooms with annual HVAC maintenance had higher odds of indoor RH over 50%. More frequent maintenance may have prevented higher humidity by quickly repairing ventilation issues. Good ventilation in classrooms is essential given the high occupancy and the impact that low ventilation rates are suggested to have on human health and learning (5, 150, 151). Given the same ventilation rate and climate, a typical classroom with 20-40 occupants will have a higher RH than an office with only a few occupants. Therefore school HVAC systems should be frequently inspected and maintained to prevent accumulation of RH, carbon dioxide (CO_2), and other indoor pollutants.

Though we measured CO_2 in classrooms during the walkthrough inspection, these measurements only give us information about the relative ventilation rates between classrooms at one point in time. Since ventilation rates vary greatly based on classroom occupancy, outdoor temperature and RH, and HVAC system operation, longitudinal measurements of CO_2 are required to understand ventilation affects RH (5).

All classrooms that did not have programmed setbacks had heat pump/refrigerant HVAC systems. Classrooms in buildings with programmed thermostat setbacks had higher odds of having RH>50% compared to those with no programmed thermostat setbacks. Thermostat setbacks normally are programmed to occur during unoccupied periods of the day, so that ventilation rates are reduced to conserve energy when the occupancy load is reduced. Therefore, we hypothesized that RH would be highest in classrooms with setbacks during unoccupied times. However, the relationship between setbacks and high classroom RH was strongest during occupied times. This result may be due to the greater influx of humid outdoor air during occupancy combined with the water vapors from exhalation and building use.

Some HVAC systems have the ability to dehumidify the fresh air supply upon intake to allow adequate ventilation during humid outdoor conditions. However, classrooms with fresh air dehumidified on intake had a higher risk of indoor RH>50%, even after controlling for outdoor humidity. Most likely, the humidistats were set to trigger dehumidification at 60% RH, a less conservative upper limit for preventing indoor mold growth than the one recommended by the IAQ Tools for Schools (51). As evidence for this theory, the highest average RH and 99th percentile value for classrooms with fresh air dehumidification was 66.2 and 62.5, respectively, compared to 81.9 and 70.5 for classrooms without fresh air dehumidification. However, the median RH for classrooms with fresh air dehumidification was 51.9 compared to 39.0 for classrooms without fresh air dehumidification, suggesting that the humid conditions in these classrooms may have necessitated extra dehumidification. Therefore, the relationship between indoor RH and fresh air dehumidification may have been a feedback loop rather than simply causal association.

In addition, the presence of an economizer in the HVAC system was associated with higher odds of having high RH, after adjustment for dehumidification of fresh air upon intake. At first glance, this result suggests that the presence of an economizer, which controls fresh air dampers to save energy by letting in more outdoor air during mild temperatures and closing dampers during extreme temperatures, may put buildings at risk of having increased humidity. However, if fresh air dehumidification was a collider rather than a confounder, adjusting for it may have biased the association between the presence of an economizer and indoor RH.

A reduction of humidity has been demonstrated in houses randomized to receive dehumidification through the addition of mechanical ventilation with heat recovery (MVHR) systems compared to the controls, which had no ventilation systems (43). All schools included in our study had ventilation systems; however, some types may be reducing humidity to extreme levels that are low enough to be harmful to human health. Classrooms with a direct expansion split system had a higher risk of RH <30% compared to those with a chilled water system. This type of system may overcompensate by providing as much dehumidification as possible, with no lower limit or method of adding moisture to the air if it becomes too dry. As the temperature of air moving across cooling coils is lowered below the dew point, water condenses out of the air stream and onto the coil. Thus, the exiting air stream is at a lower temperature and humidity ratio than the incoming air stream. Cooling to condense water from the air is called latent cooling or dehumidification. Another method of dehumidification is to add a desiccant to the air conditioning system (63). Most buildings included in the study had HVAC systems with latent cooling methods of dehumidification.

Substantial evidence exists suggesting that indoor dampness increases the risk of respiratory symptoms in building occupants by encouraging microbes to thrive and degrading building materials (1, 2). RH above 50% creates a hospitable environment for mold and dust mites, both common respiratory allergens (1, 22, 29). Environmental test houses also showed an increase in concentrations of formaldehyde, a known respiratory irritant, with increased RH. The largest increases occurred when temperature and RH were simultaneously raised and when the indoor climate shifted from heating to cooling (49).

Though indoor dampness is often the primary focus of indoor air quality improvements, some evidence exists supporting the notion that adverse health effects can occur at both extremes of RH. Low RH can cause drying and irritation of skin and mucous membranes, which may also increase disease transmission (53). Research on coronavirus survival on hard surfaces suggests viruses have better survival at both 20 and 80% compared to 50% RH (90). Influenza virus droplet transmission is inversely related to both relative and absolute humidity (56). However, in a study of common colds among students in crowded dormitories, RH did not seem to influence infection rates or duration (59).

Though our sample size allowed for clustering of the data by classroom, some models were not able to converge when the researcher added clustering by building, due to the small number of buildings (n=22). Since several covariates were collected at the building-level, introducing building-level random effects severely reduced the precision of the model since there was not enough variation to estimate the effects within all categories of these covariates. Since this was a pilot study, an expansion of this research to a larger target population of school districts may be possible with additional resources.

Missing classroom days occurred due to hygrometer malfunctions, when the instruments fell due to the wall hooks losing their adhesion. Days on which hygrometers malfunctioned had ≥90 observations and were considered incomplete. Since loss of adhesion could have been related to RH level, it was necessary to compare distributions of data completeness with relationship to RH (135).The distributions of continuous mean daily RH were similar for complete (μ=42.7, σ= 12.8) versus incomplete days (μ=42.3, σ=13.4). The dichotomous mean daily RH distributions are statistically different between complete versus incomplete days. RH from incomplete days was more likely to be within the recommended level than RH from complete days (RR=0.98 [0.97, 0.99]). However, this difference seemed unlikely to create any meaningful bias since days in which the hygrometer malfunctioned were a small proportion (0.33%) of total classroom-days. Classroom-days with no observations (n=22) were removed from the data; however, incomplete classroom-days were kept in the dataset. The mean RH from these days was calculated using the same method as for complete days.

This study illuminates upon conditions in the school environment which lead to extreme RH. Our findings suggest actionable areas of improvement for school maintenance including quarterly HVAC maintenance, choice of cooling mechanisms as they pertain to humidity control, adjustment of humidistat settings to 50% RH, and special attention to RH levels in buildings built in the 1970s to 1990s.

TABLE 7.1. DISTRIBUTIONS OF SCHOOL ENVIRONMENTAL DATA

			SCHOOL DISTRICT					
			COMBINED		PIEDMONT		COASTAL	
DAILY OBSERVATIONS		N	MEAN (μ)	S.E.	MEAN (μ)	S.E.	MEAN (μ)	S.E.
Indoor	Relative Humidity (%)	9044 classroom-days*	42.7	12.3	43.0	13.5	42.5	11.6
	Temperature (^{o}C)		22.0	1.5	22.0	1.6	21.9	1.3
Outdoor	Relative Humidity (%)	188 days	70.0	11.5	68.3	13.2	71.0	10.2
	Temperature (^{o}C)		15.8	7.1	15.4	7.0	16.0	7.1

*Missing=22 classroom-days

TABLE 7.2. ASSOCIATIONS BETWEEN BUILDING FACTORS AND HIGH (>50%) DAILY AVERAGE RELATIVE HUMIDITY LEVELS (N=9044 CLASSROOM-DAYS)

MAIN EFFECT	LEVEL	UNADJUSTED*		ADJUSTED*	
		OR	95% CI	OR	95% CI
MAINTENANCE					
Water damage[1]	Yes	0.83	(0.54, 1.26)	0.72	(0.47, 1.09)
	No	Ref.	__	Ref.	__
Frequency of HVAC maintenance[2]	Annually	1.95	(1.38, 2.76)	6.64	(3.96,11.12)
	As Needed	0.76	(0.53, 1.08)	4.74	(2.99, 7.53)
	Quarterly	Ref.	__	Ref.	__
MECHANICAL-- HEATING, VENTILATION, AND AIR CONDITIONING (HVAC) SYSTEM					
Economizer[3]	Yes	1.14	(0.81, 1.61)	3.07	(2.04, 4.63)
	No	Ref.	__	Ref.	__
Cooling mechanism[4]	Direct-expansion split system	0.06	(0.02, 0.15)	0.02	(0.01, 0.10)
	Heat pump/ refrigerant	1.29	(0.81, 2.07)	1.38	(0.91, 2.07)
	Chilled water	Ref.	__	Ref.	__

*Estimated generalized logits with referent= 30-50% relative humidity, clustered by classroom. Missing n=22 classroom-days. [1] The effect of water damage was adjusted for cooling mechanism, outdoor relative humidity (RH), and building age. Missing n=289. Water damage includes leaks, history of flooding, or visible signs of moisture/ water damage in the classroom. [2] The effect of frequency of heating, ventilation, and air conditioning (HVAC) system maintenance was adjusted for building age. [3] The effect of having an economizer in the HVAC system was adjusted for dehumidification of fresh air upon intake. [4] The effect of cooling mechanism was adjusted for heating/cooling season and building age. Heating season= outdoor temperature< 15^{o}C, transition= 15-23^{o}C, cooling season= outdoor temperature >23 ^{o}C.

TABLE 7.3. ASSOCIATIONS BETWEEN BUILDING FACTORS AND LOW (<30%) DAILY AVERAGE RELATIVE HUMIDITY LEVELS (N=9044 CLASSROOM-DAYS)

MAIN EFFECT	LEVEL	UNADJUSTED*		ADJUSTED*	
		OR	95% CI	OR	95% CI
MAINTENANCE					
Water damage[1]	Yes	0.92	(0.61, 1.39)	0.86	(0.57, 1.30)
	No	Ref.	__	Ref.	__
Frequency of HVAC maintenance[2]	Annually	0.52	(0.36, 0.77)	0.47	(0.28, 0.78)
	As Needed	1.81	(1.23, 2.66)	1.06	(0.73, 1.53)
	Quarterly	Ref.	__	Ref.	__
MECHANICAL-- HEATING, VENTILATION, AND AIR CONDITIONING (HVAC) SYSTEM					
Economizer[3]	Yes	1.21	(0.84, 1.73)	0.84	(0.60, 1.17)
	No	Ref.	__	Ref.	__
Cooling mechanism[4]	Direct-expansion split system	2.32	(1.63, 3.30)	2.59	(1.64, 4.07)
	Heat pump/ refrigerant	1.40	(0.82, 2.39)	0.92	(0.47, 1.82)
	Chilled water	Ref.	__	Ref.	__

*Estimated generalized logits with referent= 30-50% relative humidity, clustered by classroom. Missing n=22 classroom-days. [1] The effect of water damage was adjusted for cooling mechanism, outdoor relative humidity (RH), and building age. Missing n=289. Water damage includes leaks, history of flooding, or visible signs of moisture/ water damage in the classroom. [2] The effect of frequency of heating, ventilation, and air conditioning (HVAC) system maintenance was adjusted for building age. [3] The effect of having an economizer in the HVAC system was adjusted for dehumidification of fresh air upon intake. [4] The effect of cooling mechanism was adjusted for heating/cooling season and building age. Heating season= outdoor temperature< 15^{o}C, transition= 15-23^{o}C, cooling season= outdoor temperature >23 ^{o}C.

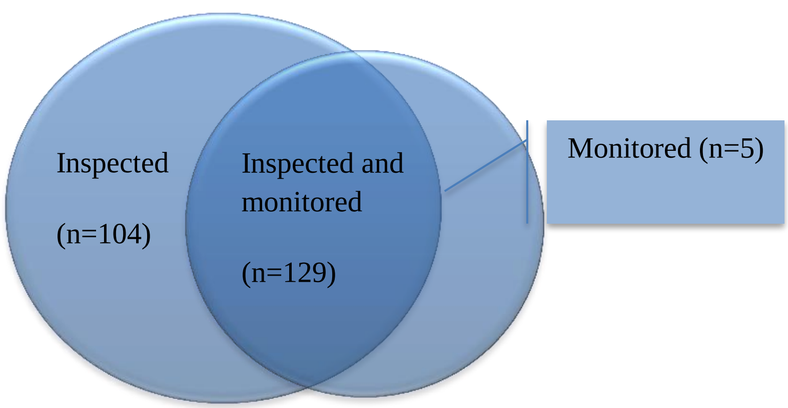
8. RESULTS: SUPPLEMENTAL RESULTS FOR AIMS 1A AND 1B

8.1. INTRODUCTION

This chapter describes the distributions of variables used in the analyses for Aims 1a and 1b. In addition, I report the results of Aims 1a here, illustrating the extent of the problem of RH control within participating classrooms. See Chapter 7 for results of Aim 1b.

Ten schools from two NC school districts participated in the study. In these schools, I inspected 233 rooms (classrooms, common areas, and offices) and continuously monitored 134 classrooms for temperature and RH (Figure 8.1). Only monitored classrooms were used in Aim 1a and 1b analyses. Four modular classrooms (trailers) were included in this analysis.

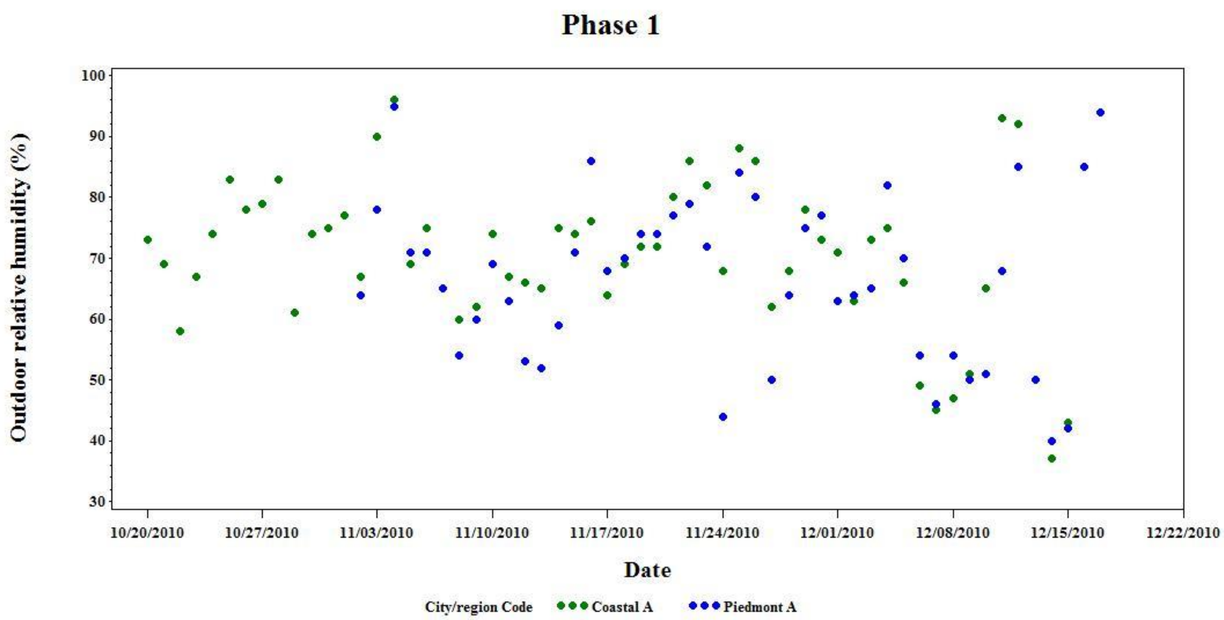
FIGURE 8.1 CLASSROOMS (N=238) PARTICIPATING IN THE WALKTHROUGH INSPECTION AND HYGROMETER MONITORING

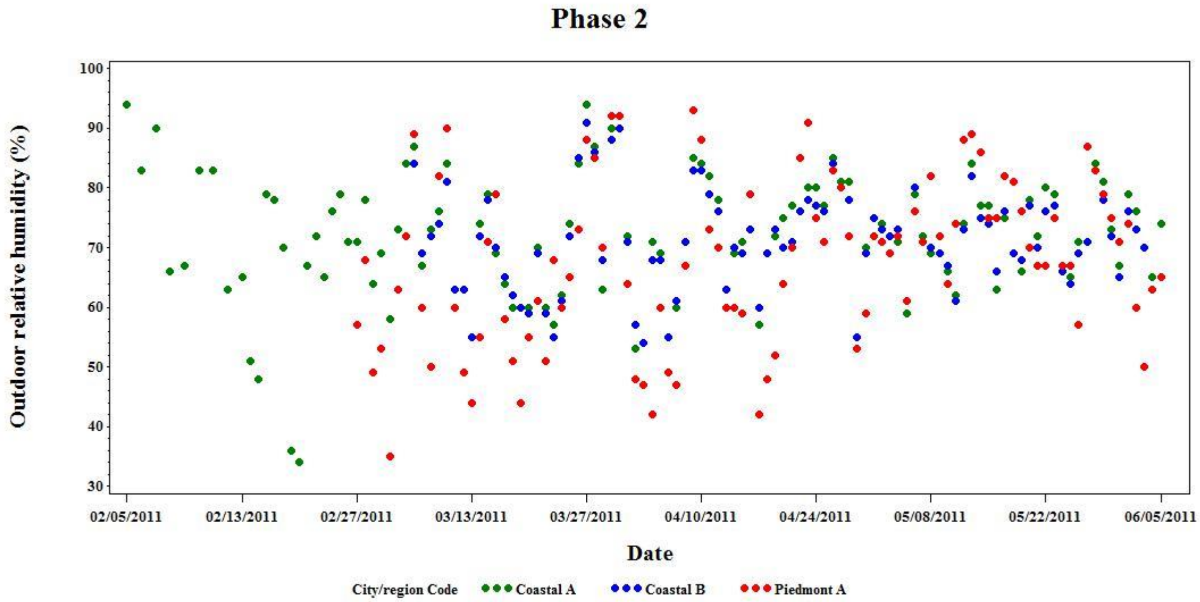


8.2. DISTRIBUTIONS OF ENVIRONMENTAL VARIABLES

During the follow-up period (Oct. 2010-Jun. 2011), the average daily outdoor RH was lower but more varied for the city located in the Piedmont (mean=68.3%, SD=13.2) compared to those located in Coastal NC (A: mean=71.0%, SD=10.7; B: mean=71.0%, SD=8.3) (Figure 8.2). Average outdoor RH overall ranged from 34 to 96%. The daily average was higher in the spring and early autumn and lowest in the winter for all locations (152).

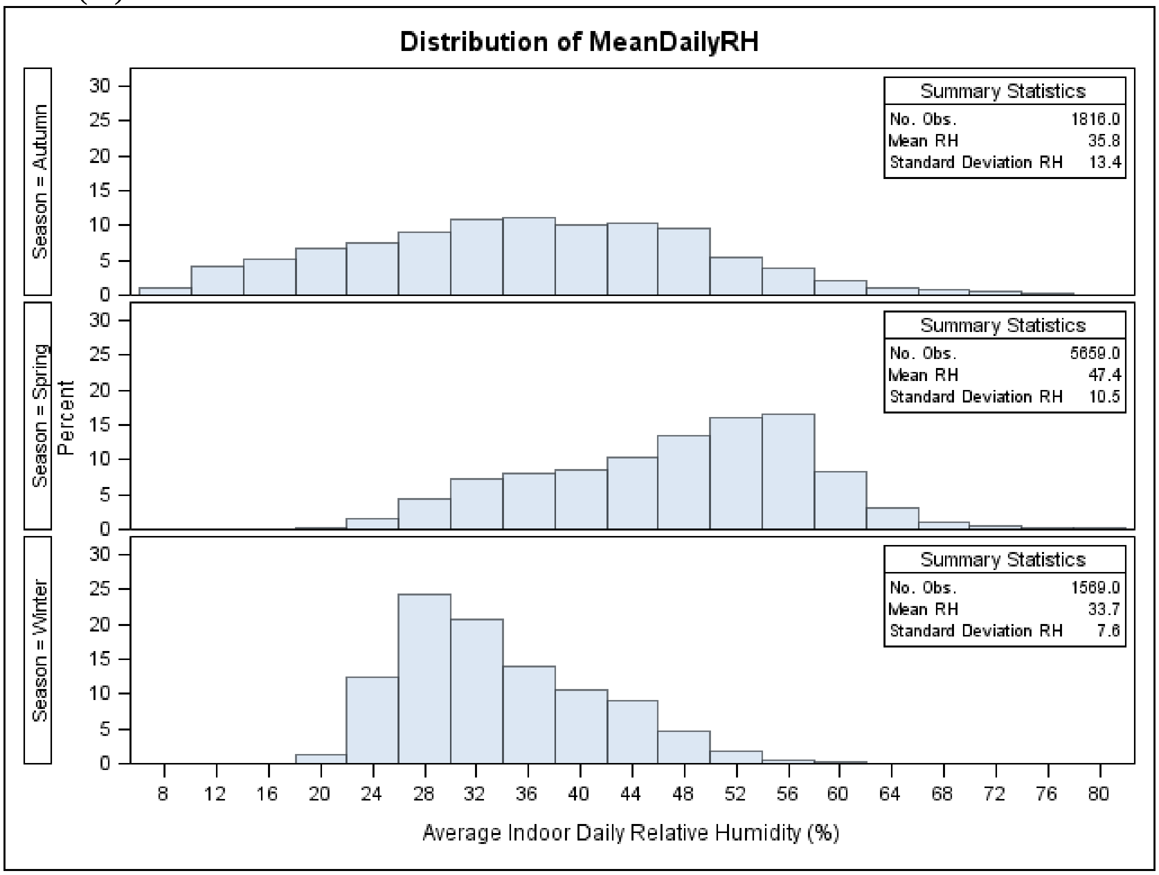
FIGURE 8.2: OUTDOOR RELATIVE HUMIDITY (%) DURING FOLLOW-UP BY CITY





In the monitored classrooms overall, indoor RH tended to be highest in the autumn and in the late spring and lowest in the winter (Figures 8.3 and 8.4). Indoor mean daily RH had a bimodal distribution. In the autumn, indoor mean daily RH had a normal distribution; whereas it has opposing skewed distributions in spring and winter (Figure 8.3).

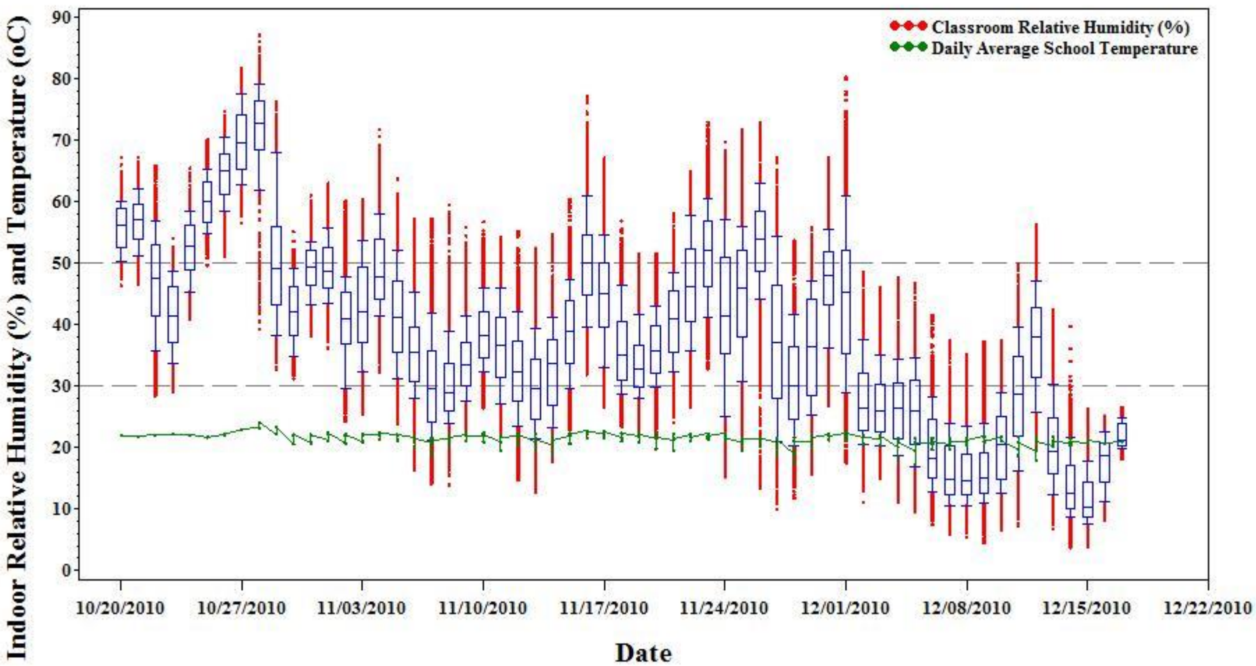
FIGURE 8.3. SEASONAL VARIATIONS IN MEAN INDOOR DAILY RELATIVE HUMIDITY (%)



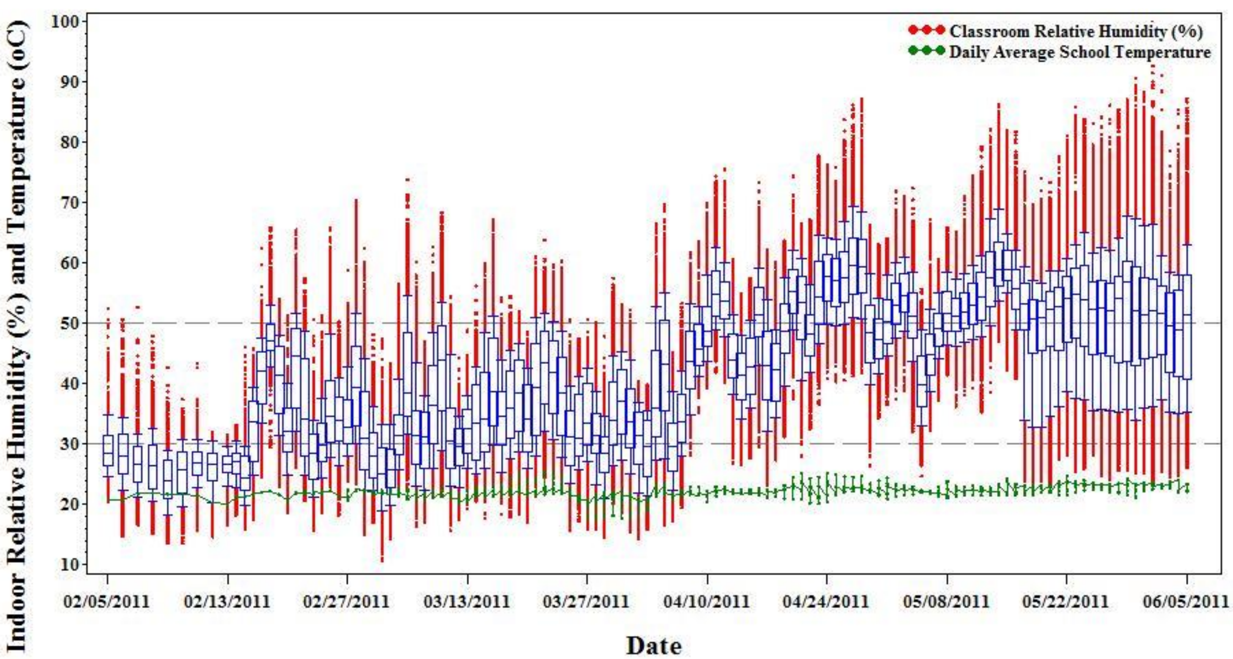
The patterns of indoor RH mirrors seasonal trends in outdoor RH; though the distribution of outdoor RH (mean= 70.0%, SD=11.5) was much higher than that of indoor RH (mean= 42.7%, SD=12.8). Mean indoor temperature, which stayed around recommended room temperature range for thermal comfort (20-23^{o}C), did not fluctuate as much as median RH (Figure 8.4).

FIGURE 8.4. OBSERVED INDOOR RELATIVE HUMIDITY AND TEMPERATURE BY PHASE*

Phase 1



Phase 2



*Whiskers indicate the 10th and 90th percentiles of relative humidity. The box ranges from the 25th to the 75th percentile, with the median indicated by the center bar.

Monitored classrooms in the Piedmont (mean=43.0, SD=13.5) had the widest variation in mean daily indoor RH compared to monitored classrooms in the Coastal region (A: mean=40.6%, SD=12.3; B: mean=47.6%, SD=6.7). Coastal City B had much less variation but also had less than half the number of observations of the other two cities. In addition, most observations for Coastal City B were taken in the spring. Thus the two Coastal cities were combined and districts were used instead of cities to compare effects of geographical location.

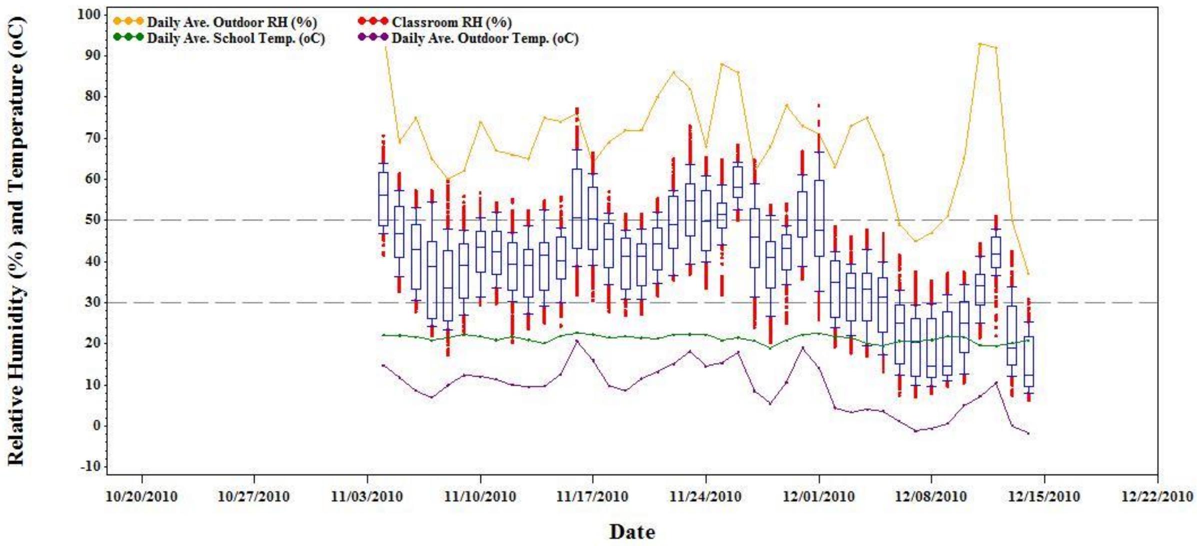
8.3. RELATIVE HUMIDITY CONTROL IN SCHOOLS: AIM 1A RESULTS

The first aim of this dissertation was to assess how many rooms per month in each school conformed to the RH range (30-50%) recommended for controlling asthma triggers. However, rather than taking a monthly average of the observed RH within each classroom and determining whether it conformed or not, the researcher determined the proportion of classroom-days with controlled RH for each school.

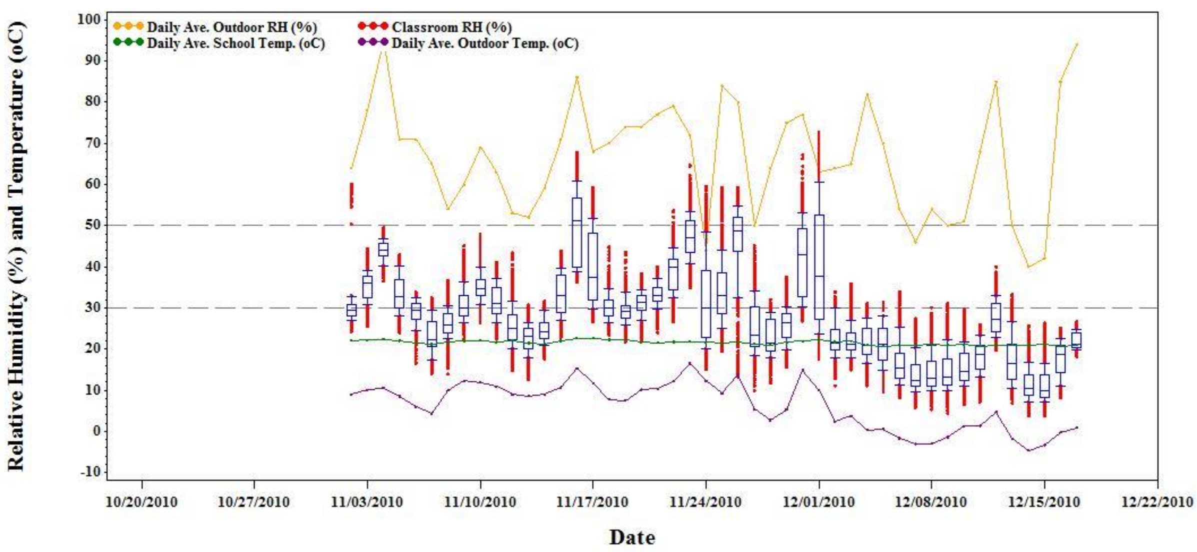
Most schools were not able to maintain recommended RH levels (30-50%) in their monitored classrooms for more than half of the follow-up period. RH appeared to be well controlled during November, but poorly controlled in December among schools participating in Phase 1 (Figure 8.5). Among Phase 2 schools, February and March had the highest percentages of classroom-days with controlled RH (Figure 8.5). The highest proportion of classroom-days with controlled RH occurred during months when the indoor climate transitioned from the heating to the cooling period. One school (WGRE-P2) had poor humidity control throughout the study period; however, this school’s follow-up period fell almost entirely within cooling days. Within schools, fluctuations in indoor RH most closely followed daily trends in outdoor temperature, whereas indoor temperature stayed fairly constant over time (Figure 8.5).

FIGURE 8.5. OBSERVED ENVIRONMENTAL PARAMETERS BY SCHOOL*
Phase 1

School= BLU-P1

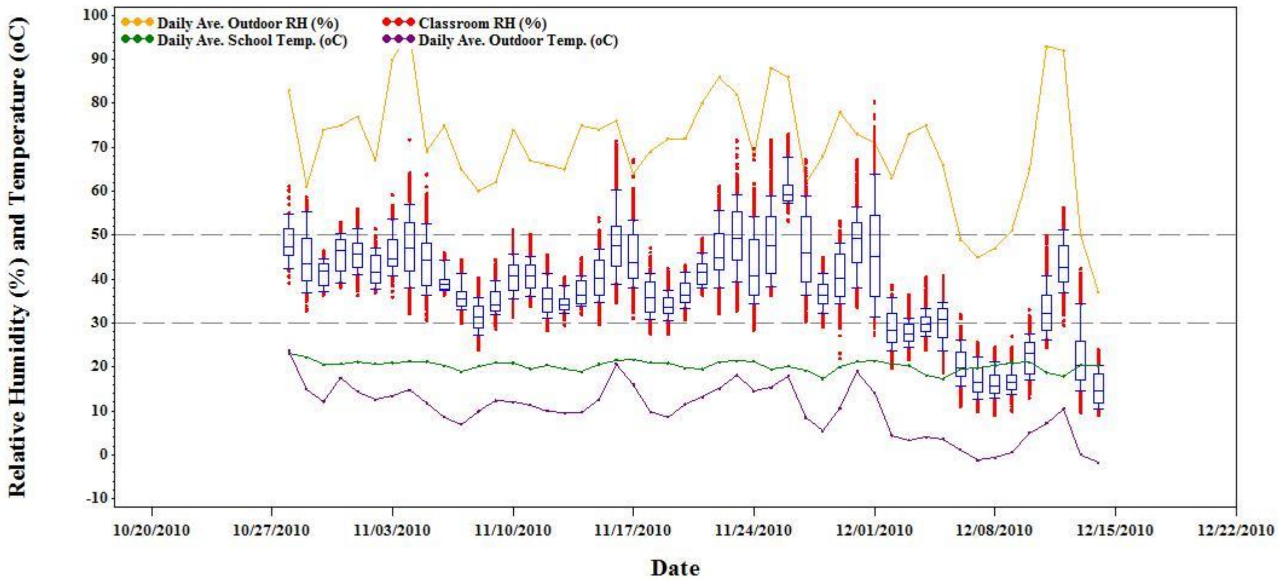


School= YEL-P1

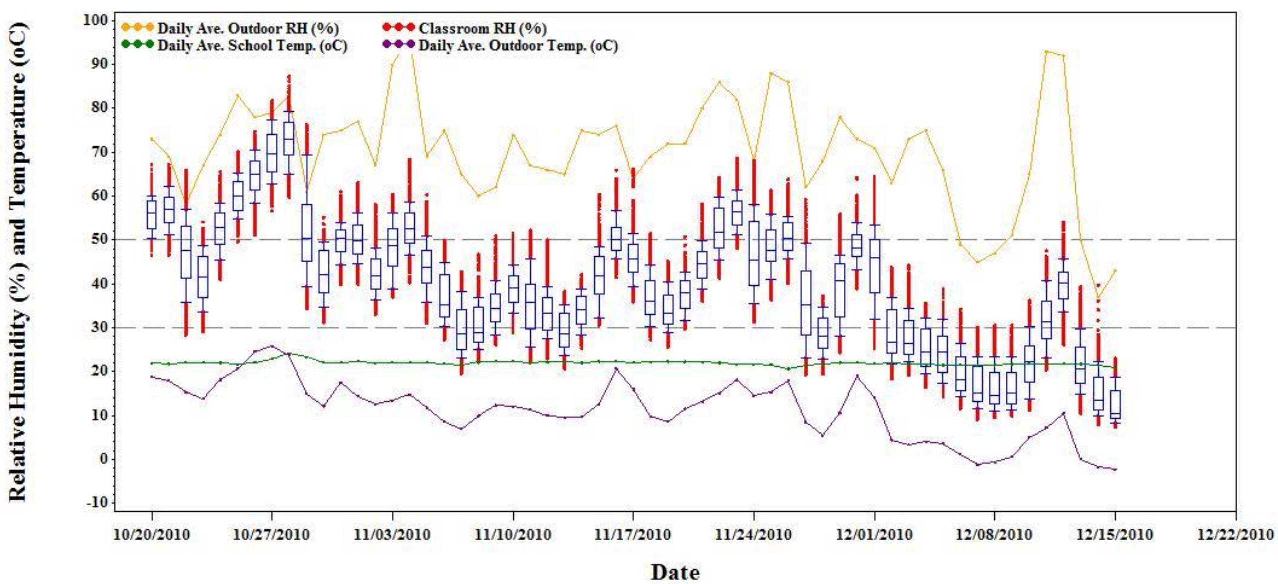


*Dotted lines indicate the recommended indoor relative humidity levels. Box plot whiskers indicate the 10th and 90th percentiles of relative humidity. The box ranges from the 25th to the 75th percentile, with the median indicated by the center bar.

School= GRE-P1

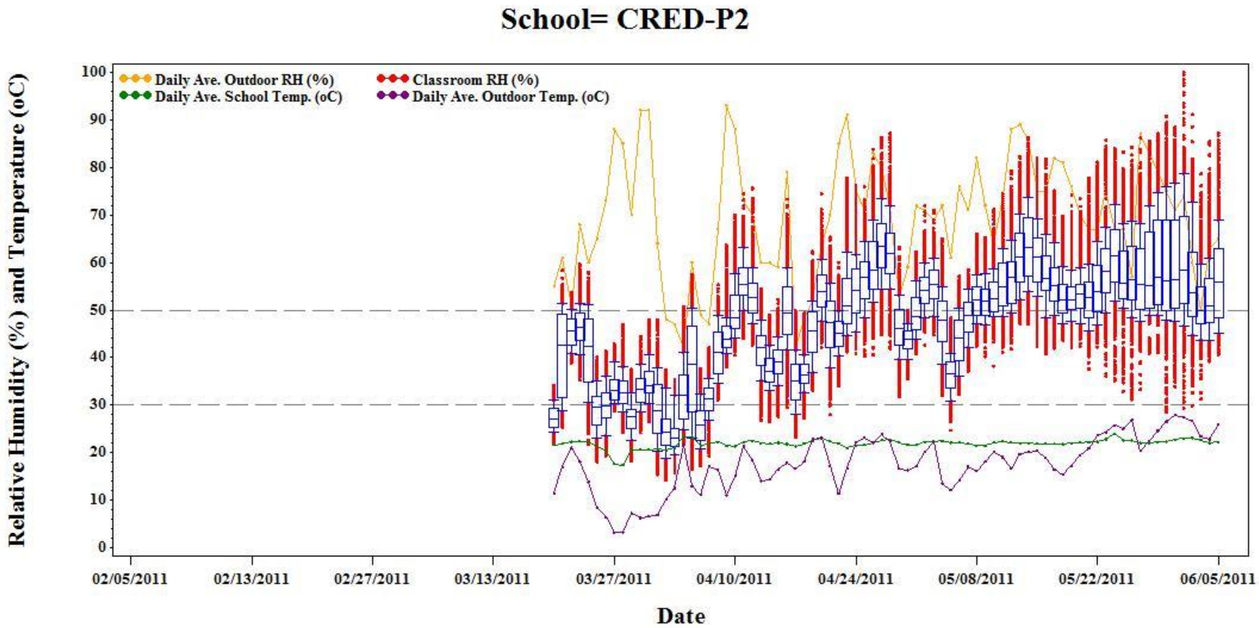


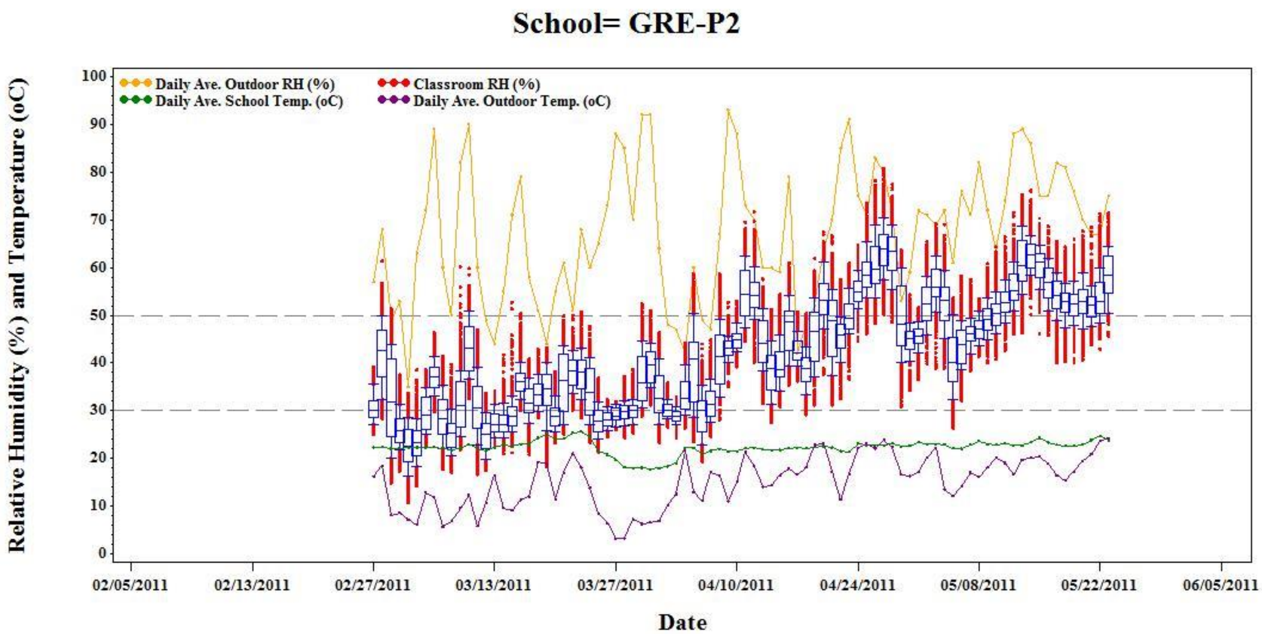
School= RED-P1



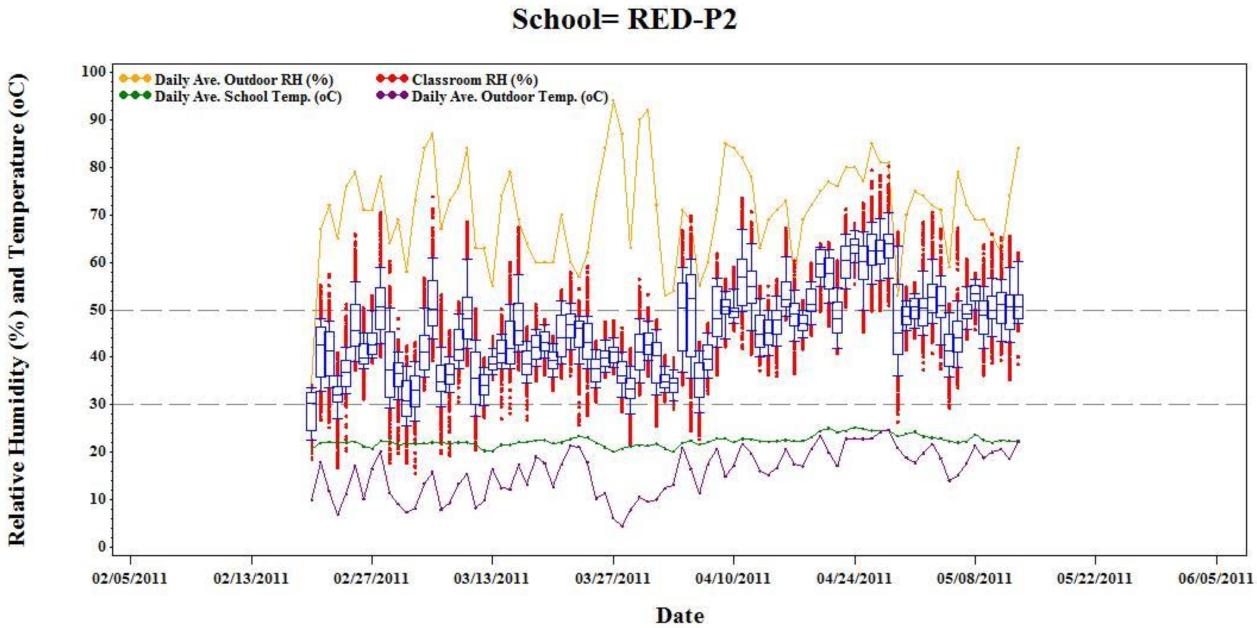
*Dotted lines indicate the recommended indoor relative humidity levels. Box plot whiskers indicate the 10^{th} and 90^{th} percentiles of relative humidity. The box ranges from the 25^{th} to the 75^{th} percentile, with the median indicated by the center bar.

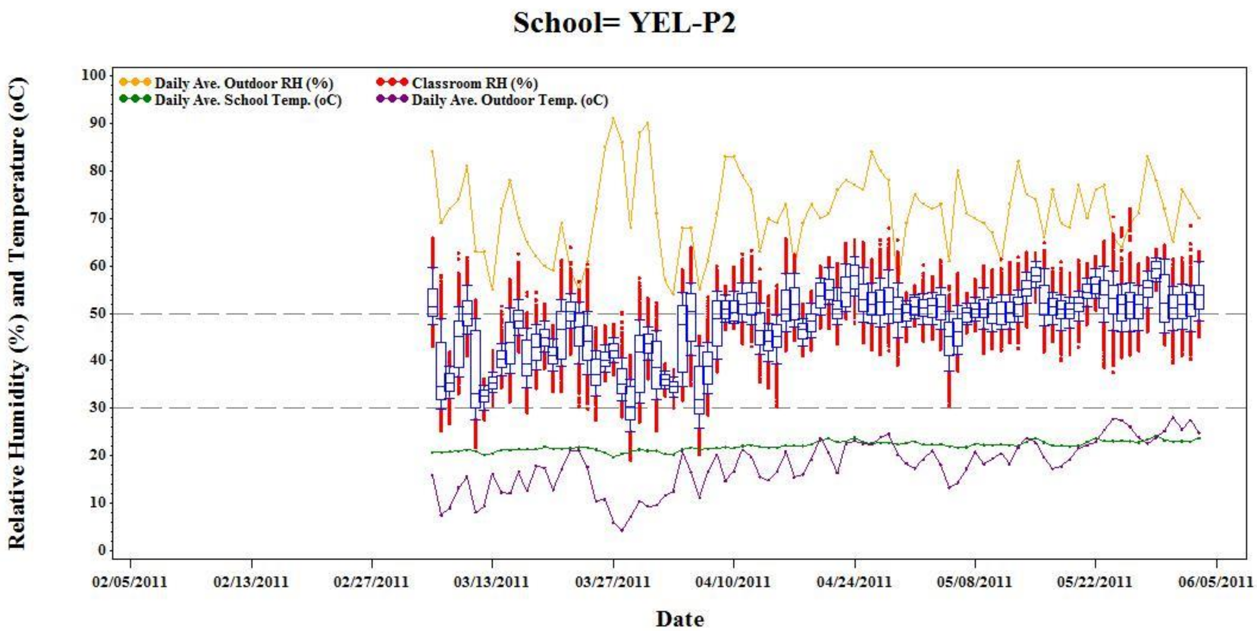
Phase 2



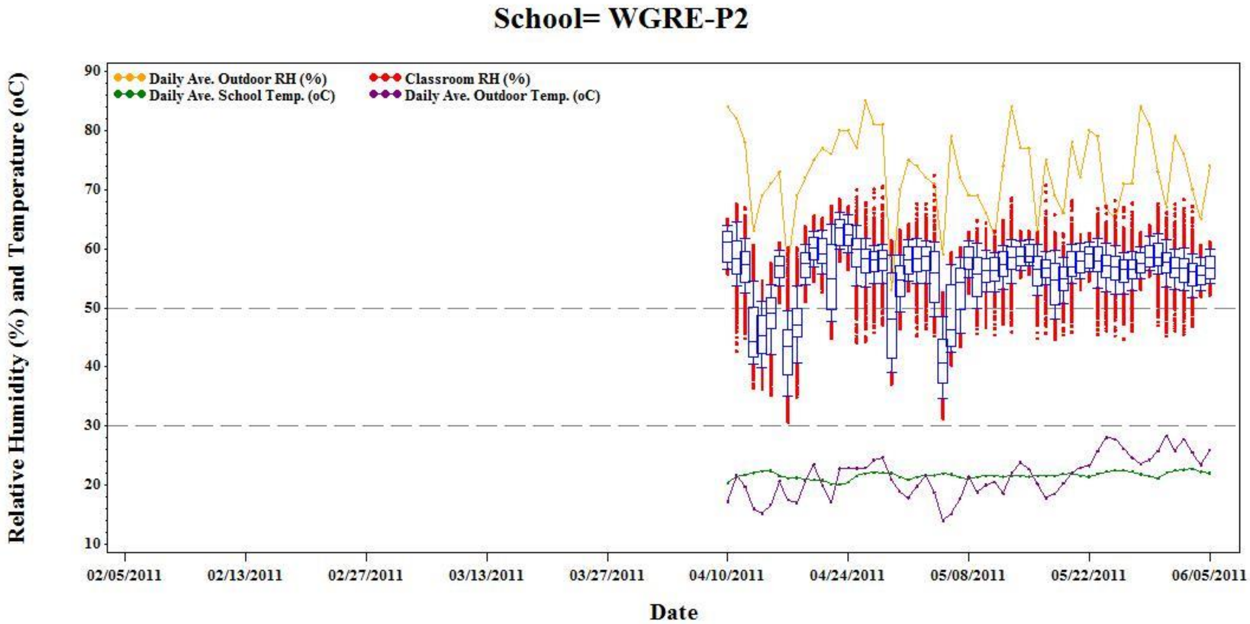


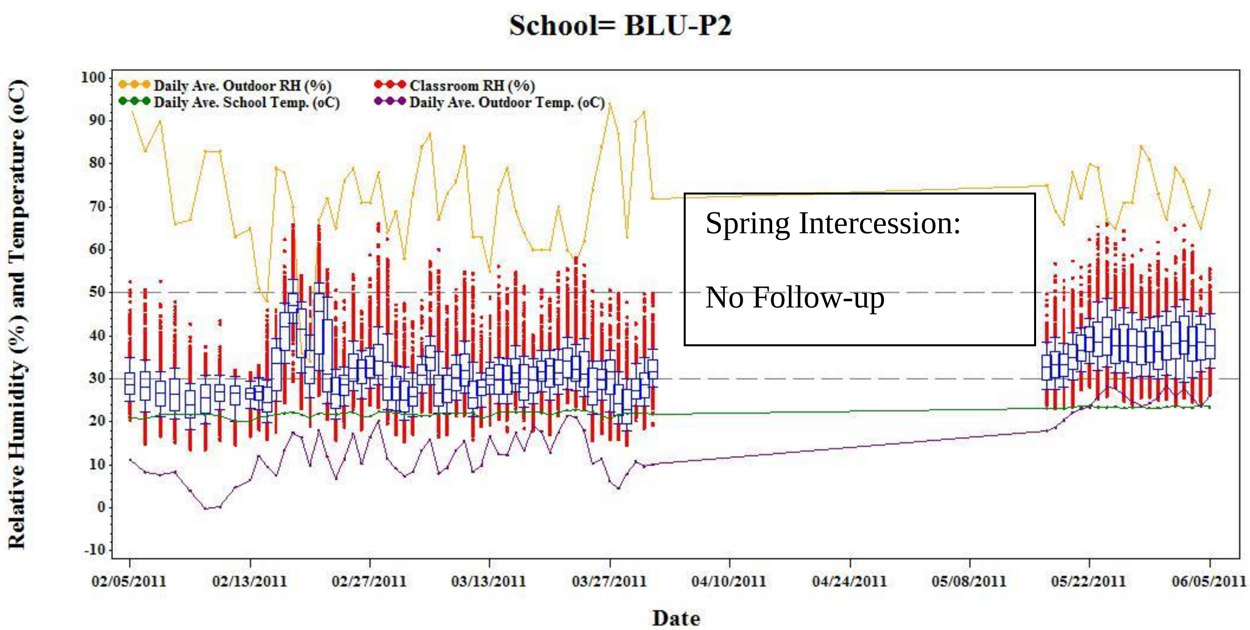
*Dotted lines indicate the recommended indoor relative humidity levels. Box plot whiskers indicate the 10th and 90th percentiles of relative humidity. The box ranges from the 25th to the 75th percentile, with the median indicated by the center bar.





*Dotted lines indicate the recommended indoor relative humidity levels. Box plot whiskers indicate the 10^{th} and 90^{th} percentiles of relative humidity. The box ranges from the 25^{th} to the 75^{th} percentile, with the median indicated by the center bar.





*Dotted lines indicate the recommended indoor relative humidity levels. Box plot whiskers indicate the 10^{th} and 90^{th} percentiles of relative humidity. The box ranges from the 25^{th} to the 75^{th} percentile, with the median indicated by the center bar.

Bivariate models revealed that classrooms with HVAC systems that dehumidified fresh air on intake had a lower risk of having low RH and higher risk of having high vs. recommended RH (Table 8.1). Compared to buildings 0 to 10 years old, buildings that were 11to 40 years old had a higher odds of RH <30% and a lower odds of RH >50% vs. recommended RH. The following factors had a null association with either extreme category of RH: building occupancy, school district, presence of an economizer in the HVAC system, broken HVAC system, refrigerant cooling mechanism (compared to chilled water), and buildings aged >40 years old compared to buildings 0 to 10 years old.

TABLE 8.1. UNADJUSTED ODDS RATIOS (OR) FOR HIGH AND LOW VS. RECOMMENDED DAILY RELATIVE HUMIDITY, N=9044 CLASSROOM-DAYS*

		Occupied				Unoccupied			
Building-related factors		Low (<30%) vs. Recommended (30-50%)		High (>50%) vs. Recommended (30-50%)		Low (<30%) vs. Recommended (30-50%)		High (>50%) vs. Recommended (30-50%)	
		OR	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*
Outside Relative Humidity	*(10 unit increase)*	0.58	(0.48, 0.69)	1.70	(1.57, 1.83)	0.62	(0.55, 0.71)	1.49	(1.43, 1.55)
School district/ Geographic location	*Piedmont*	0.99	(0.65, 1.49)	1.64	(1.17, 2.30)	1.34	(0.93, 1.94)	1.29	(0.92, 1.82)
	Coastal	Ref.	__	Ref.	__	Ref.	__	Ref.	__
Building/ building wing age (years)	*>40*	0.77	(0.37, 1.63)	0.76	(0.49, 1.18)	1.06	(0.55, 2.04)	0.66	(0.44, 0.98)
	31-40	4.70	(2.32, 9.48)	0.29	(0.12, 0.66)	4.16	(1.96, 8.83)	0.23	(0.11, 0.51)
	11-20	3.70	(2.09, 6.58)	0.31	(0.19, 0.51)	3.47	(1.98, 6.10)	0.23	(0.14, 0.38)
	0-10	Ref.	__	Ref.	__	Ref.	__	Ref.	__

Frequency of HVAC maintenance	*Annually*	0.19	(0.13, 0.29)	2.37	(1.67, 3.37)	0.52	(0.36, 0.77)	1.95	(1.38, 2.76)
	As Needed	1.53	(1.03, 2.29)	1.07	(0.74, 1.53)	1.81	(1.23, 2.66)	0.76	(0.53, 1.08)
	Quarterly	Ref.	__	Ref.	__	Ref.	__	Ref.	__
Water damage (any) **	*Yes*	0.91	(0.59, 1.40)	0.86	(0.56, 1.30)	0.92	(0.61, 1.39)	0.83	(0.54, 1.26)
	No	Ref.	__	Ref.	__	Ref.	__	Ref.	__
Any dehumidification mechanism in HVAC system	*Yes*	1.90	(0.89, 4.05)	1.99	(1.34, 2.95)	2.30	(1.14, 4.65)	1.80	(1.26, 2.57)
	No	Ref.	__	Ref.	__	Ref.	__	Ref.	__
Economizer	*Yes*	0.96	(0.64, 1.43)	1.46	(1.04, 2.05)	1.21	(0.84, 1.73)	1.14	(0.81, 1.61)
	No	Ref.	__	Ref.	__	Ref.	__	Ref.	__
Fresh air dehumidification on intake	*Yes*	0.02	(0.01, 0.04)	2.42	(1.57, 3.74)	0.02	(0.01, 0.04)	3.36	(2.23, 5.06)
	No	Ref.	__	Ref.	__	Ref.	__	Ref.	__

Setback	*Yes*	0.83	(0.31, 2.23)	3.48	(1.89, 6.38)	0.93	(0.40, 2.20)	2.79	(1.77, 4.40)
	No	Ref.	__	Ref.	__	Ref.	__	Ref.	__
Cooling mechanism	*Direct-expansion split system*	3.21	(2.17, 4.75)	0.05	(0.02, 0.14)	2.32	(1.63, 3.30)	0.06	(0.02, 0.15)
	Heat pump/ refrigerant	1.76	(1.02, 3.04)	1.15	(0.72, 1.85)	1.40	(0.82, 2.39)	1.29	(0.81, 2.07)
	Chilled water	Ref.	__	Ref.	__	Ref.	__	Ref.	__
Heating/Cooling Season	*Cooling*	0.84	(0.25, 2.79)	2.14	(1.55, 2.95)	0.52	(0.16, 1.69)	1.82	(1.3, 2.55)
	Transitional	Ref.	__	Ref.	__	Ref.	__	Ref.	__
	Heating	14.77	(9.96, 21.92)	0.045	(0.03, 0.07)	12.44	(9.31, 16.63)	0.04	(0.03, 0.05)

*Estimated generalized logits with (30-50%) as the referent using SurveyLogistic, clustered by classroom. Missing n=22 classroom-days. **No observations were recorded after June 21. Study phase indicates the two separate waves of data collection. ǂMissing n=289; Water damage includes leaks, history of flooding, or visible signs of moisture/ water damage in the classroom.

9. RESULTS (AIM 2)

9.1. ASTHMA CONTROL TEST$_{TM}$ (ACT)

The Asthma Control Test$_{TM}$ (ACT) was self-administered to 18 participants once a month during follow-up (127). Phase 1 participants completed one ACT each. Phase 2 participants completed up to three ACTs, depending on their enrollment dates. ACT scores ranged from 12 to 25, with only four scores ≤ 19, indicating not well controlled asthma. The ACT scores and number of observations were higher for Phase 2 (n=28, mean=23.5, SD=1.80) than Phase 1 participants (n=8, mean =19.75, SD=4.27). Overall scores were lowest for questions about rescue medication use and self-rated asthma control.

TABLE 9.1. AVERAGE ASTHMA CONTROL TEST$_{TM}$ (ACT) SCORES BY PHASE (127).

ACT Question	Phase 1		Phase 2		Total	
	Mean	SD	Mean	SD	Mean	SD
1.Time wasted	4.4	0.5	4.9	0.3	4.8	0.4
2.Shortness of breath	4.0	1.4	4.6	0.5	4.5	0.8
3.Night awakenings	3.8	1.3	4.9	0.4	4.6	0.8
4.Rescue medication	3.8	1.0	4.6	0.6	4.4	0.8
5.Self-rated control	3.9	1.0	4.5	0.8	4.4	0.9

9.2. WEEKLY HEALTH DIARIES

Though at enrollment, only 18 participants reported having previously diagnosed asthma, 34 participants reported asthma-like symptoms in their Weekly Health Diaries (Table 9.2). Out of all asthma-like symptoms, shortness of breath was the most common. The proportion of participants reporting cold and allergy symptoms was over five times the proportion of those reporting asthma-like symptoms. Out of all cold and allergy symptoms, stuffy nose was the most common. As seen in the enrollment survey data, the proportion of participants with any symptoms was higher for Phase 1 compared to Phase 2 participants indicating that Phase 1 participants had a poorer health status than Phase 2 participants.

TABLE 9.2. DISTRIBUTIONS OF ASTHMA, COLD, AND ALLERGY SYMPTOMS BY PHASE

	Total		Phase 1		Phase 2		Comparison	
Symptoms	Participants, (n)	Person-days (n=8569)*, (%)	Participants, (n)	Person-days* (n=1634), (%)	Participants, (n)	Person-days* (n=6935), (%)	χ^2**	p-value
Any asthma	34	4.50	15	10.83	19	3.01	194.36	<.0001
Wheezing	20	1.77	7	3.37	13	1.40	34.78	<.0001
Chest pain	12	0.78	4	0.86	8	0.76	4.64	0.0981
Tightness in chest	18	1.77	6	3.86	12	1.21	60.60	<.0001
Shortness of breath	19	2.36	6	3.61	13	2.06	18.99	<.0001
Dry cough	15	1.40	11	5.32	4	0.48	228.32	<.0001
Any cold/ allergy	94	20.95	30	26.68	64	19.60	47.96	<.0001
Productive cough	39	5.03	13	9.12	26	4.07	76.40	<.0001
Itchy eyes	46	5.80	16	6.98	30	5.52	9.11	0.0105
Itchy, scratchy throat	45	3.73	15	6.24	30	3.14	40.04	<.0001
Stuffy nose	86	13.55	26	14.32	60	13.37	4.87	0.0877
Runny nose	64	9.71	19	13.40	45	8.84	37.04	<.0001
Sneezing	59	8.46	15	9.36	44	8.25	5.99	0.0500
Sore throat	58	4.08	19	4.41	39	4.01	4.06	0.1313

*Percent of missing person-days was 7.34 for any asthma 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). ** Chi-square test for difference in proportions of person-days, with 2 degrees of freedom.

TABLE 9.3. DISTRIBUTIONS OF ADDITIONAL COVARIATES FOR AIM 2 ANALYSES*

Covariates	Total	Missing	Phase 1	Missing	Phase 2	Missing
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Presence in the school building that day	5048 (58.9)	683 (8.0)	912 (55.8)	162 (9.9)	4136 (59.6)	521 (7.5)
Windows opened that week	2258 (26.4)	615 (7.2)	273 (16.7)	143 (8.8)	1985 (28.6)	472 (6.8)

*Out of 8569 person-days (Phase 1=1634; Phase 2=6935).

Covariate distributions not described in previous sections are shown in Table 9.3. Over half of the person-time was from times when participants were working in the school building. Participants reported that they opened windows in their classrooms at least once during the week on over a quarter of person-days. See section 6.4 for descriptions of study population characteristics and sections 8.1-8.3 for descriptions of building-related factors.

Univariate associations between the outcomes and all potential covariates used in the complete case analysis model-building are shown in Table 9.4. Participants who were in the school building on a given day had a higher risk of both asthma and cold/ allergy symptoms compared to those who were not in the school building. Annual HVAC maintenance was strongly protective for both symptom groups compared to quarterly maintenance or maintenance scheduled as needed. All participants with any of the three allergy types had a higher risk of cold/ allergy symptoms compared to those with none of these allergies, but only participants with mold allergies had a higher risk of asthma symptoms. Participants in buildings that were 31-40 years old had a higher risk of asthma symptoms compared to participants in buildings that were 0-10 years old (Table 9.4).

TABLE 9.4. UNADJUSTED ASSOCIATIONS BETWEEN ASTHMA AND COLD/ ALLERGY SYMPTOMS, RELATIVE HUMIDITY, AND POTENTIAL CONFOUNDERS, RESULTS OF COMPLETE CASE ANALYSIS (N=8569 PERSON-DAYS)

		Asthma symptoms		Cold/ allergy symptoms	
Covariate	Level	N (%)	RR (95% CI)	N (%)	RR (95% CI)
Relative humidity	Low (<30%)	90 (23.32)	1.11 (0.92, 1.34)	326 (18.16)	0.99 (0.92, 1.07)
	High (>50%)	109 (28.24)	1.07 (0.90, 1.27)	554 (30.86)	1.00 (0.92, 1.09)
	Recommended (30-50%)	171 (44.30)	Ref.	858 (47.80)	Ref.
Presence at work that day	Yes	256 (66.32)	1.15 (1.00,1.32)	1214 (67.63)	1.20 (1.09, 1.32)
	No	125 (32.38)	Ref.	569 (31.70)	Ref.
Frequency of HVAC maintenance	Annually	17 (4.40)	0.17 (0.03,0.90)	305 (16.99)	0.94 (0.51, 1.75)
	As Needed	82 (21.24)	0.99 (0.35, 2.81)	420 (23.40)	1.43 (0.86, 2.39)
	Quarterly	271 (70.21)	Ref.	1013 (56.43)	Ref.
Programmed setbacks	Yes	349 (90.41)	0.54 (0.08, 3.55)	1681 (93.65)	0.86 (0.29, 2.57)
	No	21 (5.44)	Ref.	57 (3.18)	Ref.

Economizer	Yes	149 (38.60)	1.08 (0.50, 2.37)	754 (42.01)	1.26 (0.81, 1.94)
	No	221 (57.25)	Ref.	984 (54.82)	Ref.
Building/ building wing age (years)	>40	60 (15.54)	0.87 (0.29, 2.66)	285 (15.88)	0.63 (0.33, 1.20)
	31-40	79 (20.47)	2.65 (1.03, 6.82)	192 (10.70)	1.14 (0.66, 1.97)
	11-20	121 (31.35)	0.99 (0.38, 2.54)	651 (36.27)	0.82 (0.48, 1.39)
	0-10	110 (28.50)	Ref.	610 (33.98)	Ref.
Window opened that week+	Yes	110 (28.50)	1.10 (0.65, 1.89)	463 (25.79)	1.00 (0.78, 1.29)
	No	276 (71.50)	Ref.	1325 (73.82)	Ref.
Pollen allergy	Yes	168 (43.52)	1.34 (0.62, 2.88)	882 (49.14)	1.74 (1.15, 2.65)
	No	218 (56.48)	Ref.	913 (50.86)	Ref.
Mold allergy	Yes	160 (41.45)	2.13 (1.00, 4.52)	822 (45.79)	2.74 (1.86, 4.04)
	No	226 (58.55)	Ref.	973 (54.21)	Ref.
Dust mite allergy	Yes	176 (45.60)	2.07	869 (48.41)	2.52

			(0.99, 4.34)		(1.70, 3.74)
	No	210 (54.40)	Ref.	926 (51.59)	Ref.
Average Daily Outdoor Temperature (^oC)***	10-unit decrease	381 (98.7)	1.09 (0.95, 1.25)	1793 (99.9)	1.04 (0.97, 1.12)

TABLE 9.5. UNIVARIATE ASSOCIATIONS BETWEEN ASTHMA AND COLD/ ALLERGY SYMPTOMS AND DAYS OF THE WEEK*

	Asthma symptoms	Cold/ allergy symptoms
Day of the Week**	RR (95% CI)	RR (95% CI)
Weekend	0.83 (0.72, 0.95)	0.84 (0.76, 0.92)
Saturday	0.84 (0.71, 1.00)	0.96 (0.88, 1.03)
Sunday	0.97 (0.83, 1.12)	0.87 (0.80, 0.94)
Weekdays	1.21 (1.05, 1.38)	1.19 (1.08, 1.31)
Monday	1.04 (0.90, 1.20)	1.03 (0.96, 1.10)
Tuesday	1.04 (0.88, 1.23)	1.03 (0.97, 1.10)
Wednesday	0.98 (0.84, 1.14)	1.01 (0.95, 1.08)
Thursday	1.12 (0.96, 1.30)	0.99 (0.92, 1.05)
Friday	1.01 (0.87, 1.17)	1.11 (1.04, 1.18)

*Imputed data (m=20 imputations, n=171380 person-days) **Each day was entered individually into the model with all other days as the referent.

Weekends were protective for both asthma symptoms and cold/allergy symptoms compared to weekdays. Reported asthma symptoms were most strongly associated with Thursdays, and reported cold/allergy symptoms were most strongly associated with Fridays (Table 9.5). The researcher assumed no participants were working in the building on the weekend; thus, participants' presence or absence at school on a given day was correlated with the day of the week. For this reason, day of the week was not used in the main analysis.

10. RESULTS: PAPER 2. EFFECTS OF CLASSROOM RELATIVE HUMIDITY CONTROL ON TEACHERS' RESPIRATORY SYMPTOMS

10.1. INTRODUCTION

Though teaching is normally considered an occupation with few, long-term health hazards, teachers have a high prevalence of current asthma compared to other non-industrial, occupational groups. In one study, middle and high school teachers had a similar prevalence of current asthma to blue collar workers (8.8% vs. 8.6%) but a much higher prevalence of recent chest (19.3% vs. 7.2%) and nasal symptoms (8.1% vs. 2.7%) (104). National Health and Nutrition Examination Survey (NHANES) data (2000-2004) revealed that teachers had the highest asthma prevalence of any occupation surveyed [prevalence=13.1% (7.8-21.2)] next to miners (103). Other studies have similarly found a high prevalence of current asthma among teachers (71, 105). The California Teachers Study found that 7.6% of teachers reported asthma symptoms that required medical intervention within the past year (71). Two studies of work-related asthma cases in occupational surveillance systems found that the highest proportion of work-related asthma cases were among teachers (or educational services employees) (106, 107). School exposures most commonly implicated as asthma triggers included dust, mold, and other IAQ issues (107).

Asthma is a common, chronic illness in which the flow of air to the lungs is restricted because of inflammation and constriction of the bronchi. Primary symptoms include wheezing, shortness of breath, dry cough, and night wakening due to inability to breathe (47). Work-related asthma, the primary focus of this research, occurs when a worker's pre-existing or newly diagnosed asthma is exacerbated by "non-specific" factors in the work environment (69).

Environmental factors that can trigger asthma exacerbation in susceptible individuals include viral infections; aeroallergens such as mold, dust mites, and pet dander; and chemical or particulate irritants (21, 24, 47, 50, 70, 79). In addition, changes in ambient temperature and humidity may cause inflammation or hyper-responsiveness or may influence the airborne concentrations of known asthma triggers such as pollutants or allergens like molds and pollens (47, 84).

Evidence of asthma triggers related to high humidity was found in NC middle schools statewide (153). Warm, humid climates, such as can be found in NC, create an additional burden for existing school maintenance operations trying to improve indoor air quality. Challenges typical of most schools include high occupancy, multipurpose buildings, multiple ventilation needs within one building, and difficulty in securing maintenance and construction funds. Building maintenance problems in schools including inadequate ventilation, flooding, leaks, spills, and/ or improper drainage may cause excess dampness (27). Resource-poor schools may forgo necessary repairs and maintenance and are often located in areas at risk for flooding (66). If humidity control is not incorporated in school designs, even Leadership in Energy and Environmental Design (LEED)-certified schools may quickly develop indoor air quality problems (154).

The EPA recommends that schools should keep indoor relative humidity (RH) levels between 30-50% for optimum indoor air quality (51). Both low (<30%) and high (>50%) RH has been linked to adverse health effects in the literature. High RH may cause adverse health effects due to increases in fungal growth, dust mite reproduction and defecating, and chemical emissions from furniture and building materials (27, 39-41, 44, 49, 155, 156). Several literature reviews have concluded that indoor dampness was associated with asthma exacerbation, cough, wheeze, bronchitis, and upper respiratory infections (1, 2, 157). Low RH can cause drying and irritation of skin and mucous membranes which may make the host susceptible to viral infection (53, 56, 90, 158). Both excessive moisture and excessive dryness may also increase upper respiratory infection transmission due to increased viral survival and droplet transmission (55, 56, 58, 93, 94). Since one study in crowded dormitories concluded that RH did not seem to influence infection rates or duration of the common cold, this effect is likely dependent on type of virus (59).

The purpose of the "Free to Breathe, Free to Teach" study was to estimate the effect on teachers' respiratory symptoms of classroom RH above or below the recommended level (30-50%). In addition, we describe the effects of other indoor air quality factors on respiratory symptoms.

10.2. MATERIALS AND METHODS

The "Free to Breathe, Free to Teach" study was a longitudinal cohort study of the health effects of indoor air quality (IAQ) factors on full-time teachers. Data were collected in two phases, with Phase 1 running from October 16 to December 10, 2010 and Phase 2 running from February 6 to June 11, 2011. Four schools participated in Phase 1, and six schools participated in Phase 2.

Administrators from 20 NC school districts were invited to enroll their districts as study sites, based on referrals from industrial hygienists and previous interest in the EPA's "IAQ Tools for Schools," an educational program about school indoor air quality. Superintendents from two school districts responded and met the eligibility requirements (at least three school principals interested in participating in the project). A contact person from each district maintenance office was designated as our liaison.

To develop administrative commitment and promote community ownership of the research, the district liaison chose which schools 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 (primary, middle, and high school) and resource levels (112). Each liaison was given a recruitment letter and letter of consent to send via email to principals of potential schools. Once their schools were enrolled, each principal assigned a school liaison, who fielded questions between us and members of the school community.

Participants were convenience sampled from participating schools with the goal of enrolling as many participants as possible (112). All full-time teachers who worked at least 30 hours per week at the participating school were invited to participate in the study via an email and informational enrollment training explaining the study procedures.

To be enrolled in the study, teachers were required to attend a brief training on study procedures, risks, and benefits; sign a consent form; give contact information; and complete the online enrollment survey. All consented teachers were assigned unique participant identifiers. During Phase 1, enrollment trainings were scheduled at the convenience of the principals. Since trainings scheduled during staff meetings had better attendance and were more efficient at recruiting participants, Phase 2 school enrollment trainings were scheduled for the next available staff meeting before data collection. Enrollment was staggered by school based on training date.

The enrollment survey consisted of baseline questions on work history, demographics, and questions from the 2008 Behavioral Risk Factor and Surveillance System (BRFSS) "Asthma Call-back Questionnaire for Adults" which assessed home exposures and self-reported chronic respiratory diagnoses (115). Demographic categories for income, ethnicity, education, and race closely matched those used for the 2009 American Community Survey (116). The enrollment survey was administered through Qualtrics Research Suite (130).

10.2.1. Outcome measurement

During follow-up, participants recorded daily cold/ allergy and asthma-related symptoms in "Weekly Health Diaries" at the start of the following work week. Phase 1 Weekly Health Diaries were self-administered via paper surveys; and Phase 2 Weekly Health Diaries were administered online through Qualtrics Research Suite (130). Asthma was our primary outcome of interest due to the life-long debilitating effects of asthma and the comparatively high prevalence of asthma, including work-related asthma cases, among educational workers compared to other non-industrial workers (71, 103-107). Because allergies and viral respiratory infections may precede development of asthma and also may cause teacher absences from school, we were also interested in cold/ allergy symptoms (159). Since cold and allergy symptoms were indistinguishable from one another without other clinical diagnostic tools, they were grouped together for analysis.

To capture asthma symptoms in undiagnosed teachers and weekly symptom variations in asthmatic teachers, questions about specific asthma symptoms were included in the Weekly Health Diaries for all participants. Participants reported symptoms for each day during 4 to 12 weeks of follow-up. Questions for the Weekly Health Diaries were modeled on questions from the Rural Health Survey (117).The diaries also asked about allergy medication usage, absences due to illness, hours worked each week, and temporary environmental factors such as carpool duty or dehumidifier use. The main outcome "any asthma symptoms" was defined as positive for each person-day if the participant reported having wheezing, chest pain, tightness in chest, shortness of breath, and/or dry cough. The main outcome "any cold/allergy symptoms" was defined as positive for each person-day if the participant reported having productive cough (phlegm); itchy eyes; itchy, scratchy throat; stuffy nose; runny nose; sneezing; and/or sore throat. Observations where participants reported cold/allergy symptoms with fever and cough or sore throat were excluded, since the combination of symptoms fits the Centers for Disease Control (CDC) case definition for influenza-like illness (136).

10.2.2. Exposure Assessment

At the start of follow-up, classrooms and common areas were inspected according to the EPA's IAQ Tools for Schools Walkthrough Inspection procedures (51). During these baseline inspections, potential asthma triggers were noted. IAQ parameters were measured, with an emphasis on factors affecting classroom RH. We retrospectively surveyed district maintenance liaisons about building operations policies and heating, ventilation, and air conditioning (HVAC) equipment in operation during our longitudinal data collection period.

With the permission of participants, each classroom was monitored by Extech data logging hygrometers programmed to record indoor RH and temperature at 15 minute intervals. Hygrometers were placed near the participants' breathing zones in the classroom, at their desks or near the board or podium. Before and during data collection, hygrometers were checked for accuracy and precision with numerous tests against the sling psychrometer as a gold standard.

Though RH data were collected from multiple classrooms for some participants, RH was limited to the participants' primary classrooms (defined as the classroom in which each participant spent the most time during a normal week) for this analysis, since the participants' classroom schedules were not collected longitudinally. Relative humidity observations were averaged over each day by classroom. Since high and low RH have different hypothesized mechanisms of disease development, classroom daily average RH levels were classified as low (<30%) vs. recommended (30-50%) and high (>50%) vs. recommended (30-50%).

In the Weekly Health Diaries, participants were asked to record the number of hours (to the nearest half-hour) spent at school each day to determine whether or not they were “exposed" to classroom RH levels for that day. We defined presence in the school building as “1” if the participant reported any hours (>0) in the school building that day. Participants were instructed, “For days in which you did not enter your school building, write "0."” Therefore, if a participant was away on a fieldtrip or conference, she would be counted as not present in the school building that day.

The North Carolina State Climate Office provided daily averages of outdoor RH and temperature corresponding to the cities and time periods included in the study (114). Outdoor temperatures were used as guides for when heating and cooling would be requested in mechanically ventilated buildings as follows: heating days= less than 15^{o}C, transition days= 15-23^{o}C, cooling days= more than 23 ^{o}C. Definitions for heating and cooling days came from the daily average outdoor temperatures that were estimated to produce indoor temperatures within 80% of the Adaptive Comfort Standards created by Brager, et al. for a naturally ventilated building (138).

The NC Department of Public Instruction provided teacher demographic data aggregated at the district level (133). Each school district provided information on teacher tenure and highest degree of education, by school.

10.2.3. Statistical Methods

We aimed to estimate the association between classroom average RH levels on day=t and self-reported respiratory health outcomes (any asthma symptoms and any cold or allergy symptoms) on that same day. Both bivariate and multivariate models (Equation 1) were fitted with Generalized Estimating Equation (GEE) models using the modified Poisson regression approach for correlated binary data, as described by Zou and Donner (144, 145) . Since outcome occurrences (event=1) closer in time had a higher correlation than outcome occurrences further apart in time, an autoregressive (AR) error correlation matrix was used to model time-dependence (135).

$$log\ (\mu_{it}) = \hat{\beta}_0 + \hat{\beta}_n x_{it}^{(n)} \qquad \text{(Equation 1)}$$

where μ_{it} =average risk of outcome=1, x=observed exposure/covariate, n= number of covariates, t=time(days), i=individual participant.

Models were built using a type of backward selection, with *a priori* criteria specified for order of removal of covariates. Covariates assessed for inclusion are listed in Table 10.2. For the non-imputed dataset, the variables were left out of the model if their removal had the following effects (in order of importance): changed the main estimate by < 5%, decreased the quasi-likelihood information criteria (QIC) and QICu (thus improving the model fit), and improved precision of the main estimate (146). For the imputed dataset, the variables were left out of the model if their removal produced <5% change in estimate and improved precision, since the procedure used to combine the imputation estimates could not produce a summary QIC.

Due to missing data for the outcomes (7.34 % for asthma symptoms; 7.67% for cold/ allergy symptoms), missing data were imputed through multiple imputation, which is expected to yield more accurate estimates than complete case analysis (141). We created imputation models (m=20) that included measured potential confounders associated with both the exposure and outcome in previous studies, all variables correlated with the outcomes, and all variables strongly associated with the risk of missing outcome. The continuous exposure variable for average daily indoor RH was also imputed using variables associated with the risk of missing exposure and covariates associated with the exposure as described in a prior paper. The imputed average daily indoor RH was then categorized as low (<30%), recommended (30-50%) or high (>50%). We compared results from the model-building process using the original and the imputed datasets and found the results to be similar.

The final models for the imputed data used 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 average daily relative humidity observation from two days before the outcome observation (day=t-2). Data were managed, imputed and analyzed in SAS V9.3 (111).

Our primary interest was in the association between measured, average, classroom daily RH and risk of respiratory symptoms for that day. Since teachers who were absent from school on a given day were not exposed to the RH measured on that day, in unlagged analyses we focus on the association between average daily RH and asthma symptoms among those present on a given day. In lagged analyses, we consider teachers present on the lagged exposure day and symptoms 1 day (or 2 days) later.

10.3. RESULTS

Of the 569 full-time classroom teachers invited to participate, 122 (21%) consented, completed the baseline questionnaire (enrollment survey), and were found to be eligible. The retention rate for participants was 85.2% who stayed until the end of follow-up. The survey completion rate was higher for Phase 2 (77.9%) than Phase 1 (69.4%), despite the longer follow-up time in Phase 2 compared to Phase 1. The prevalence of self-reported asthma among all participants at baseline was 14.8%. The prevalence of self-reported atopy (all allergy types) among all participants at baseline was 52.5%. Participants were primarily female, non-smokers, who self-identified as non-Hispanic and white/Caucasian. At baseline, almost all participants reported some home exposures that would be considered IAQ issues (Table 10.1). Compared to the target population of all full-time, classroom teachers at participating schools, participants were more likely to have very little or very extensive teaching experience. A higher proportion of study participants had advanced degrees, were female, and self-identified as white/Caucasian compared to the eligible population. Because of the lack of school-specific demographic data, these results are difficult to interpret.

Participants spent most of their work week in their primary classrooms, where the hygrometers were placed. The average time that participants reportedly spent in their primary classrooms was 39.4 hours (standard deviation (SD) = 9.34). Phase 1 participants spent slightly less time [mean= 38.8 hours (SD= 11.3)] in their primary classrooms compared to Phase 2 participants [mean=39.7 hours (SD=8.4)].

The risk of asthma symptoms among those present in the school building and having high classroom RH was 1.09 (0.84, 1.35) times the risk of asthma among those present in the school building and with recommended RH, after controlling for outdoor temperature. The risk of asthma symptoms among those present in the school building and having low classroom RH was 1.09 (0.81, 1.37) times the risk of asthma among those present in the school building and with recommended RH (Table 10.3).

The risk of cold/ allergy symptoms among those present in the school building and having high classroom RH was equivalent to the risk of cold/ allergy among those present in the school building with recommended RH [RR=1.00 (0.90, 1.09)]. The risk of cold/ allergy symptoms among those present in the school building and having low classroom RH was also equivalent to the risk of cold/ allergy among those present in the school building with recommended RH [RR=1.00 (0.89, 1.11)] (Table 10.3).

Presence in the school building was independently associated with an increased risk [RR =1.17 (0.96, 1.42)] of reported asthma compared to not being present in the school building, however the confidence intervals included the null. Presence in the school building was also independently associated with an increased risk of cold/allergy symptoms [RR=1.19 (1.08, 1.32)]. Teachers in classrooms with heating, ventilation, and air conditioning (HVAC) systems maintained on an annual basis had a much lower risk of daily asthma symptoms than teachers in classrooms with quarterly scheduled HVAC maintenance [RR= 0.19 (0.05, 0.80)] (Table 10.2).

The association between high RH and asthma symptoms was slightly weaker after adding the one and two day exposure lags. The association between low RH and asthma symptoms was slightly stronger after adding the one and two day exposure lags. However, the associations between excessive relative humidity and cold/ allergy symptoms were equivalent between all exposure lag times (0- 2 days) (Table 10.3).

10.4. DISCUSSION

Among teachers who participated in our study, we found a fairly high prevalence of asthma and allergies at baseline. The prevalence of ever diagnosed asthma at baseline (14.8%) was higher among our participants than the prevalence [13.2 (12.2-14.3)] among the general population of North Carolina residents at the time (77). In addition, most daily asthma symptoms were reported by participants who had not ever been diagnosed with asthma. No participants reported new diagnoses during the data collection period. However, since the participants were recruited using a non-random sampling method, the baseline prevalence data may not be generalizable to the population of all full-time teachers.

In recent literature, evidence exists for problems with water damage and excessive dampness in schools worldwide (6-20). Though school employees spend much of the day in schools and typically many years in one building, only 10 studies on mold and water damage in school environments were found which focus on the health consequences for school employees (6-12, 21, 54, 97, 99). Seven of those focus specifically on teachers as participants (6-8, 10-12, 97). Six of those studies showed strong associations between dampness and/or mold and respiratory symptoms (8-11, 21, 97). These studies varied widely in their exposure and outcome assessment methods, and thus it would be difficult to combine their results in a meta-analysis. Most exposure assessments were based on visual inspections and mold testing, which have no standard methods and no widely recognized credentials for investigators in the United States, leading to much variation in the quality of inspections and tests (32).

In our study, we found evidence that presence in the school building increased participants' risk of respiratory symptoms, at any level of classroom RH. Both extremely high and low RH were associated with increased risk of asthma symptoms. However, neither one appeared to have an effect on cold/allergy symptoms on that same day. These data alone do not provide us with the evidence necessary to determine the mechanism by which extreme RH was associated with respiratory symptoms; however, our inspection results suggested that allergens were present in many participating classrooms. The lack of changes in association over one and two day lags suggest an acute risk factor such as allergen or chemical, rather than an infectious agent which typically requires an incubation period for symptoms to develop.

Indoor RH alone may not be a sufficient proxy measure for the intermediates such as mold, dust mites, and chemical emissions that have been more directly implicated in causing adverse respiratory health effects in schools. Poorly insulated surfaces can allow condensation to form during periods of extreme temperatures and high indoor humidity due to the temperature differential between outdoor and indoor air which causes the surface to reach the dew point (65). Condensation would make water more bioavailable to mold and dust mites for growth and reproduction and saturation of the surfaces may create more off-gassing of hazardous chemicals as the building materials come to equilibrium with the surrounding air (49, 160). Field studies demonstrated that mold may grow in less than a week if critical moisture thresholds are exceeded, depending on the climate, the mold species, and the building material or surface in question (34-36). Therefore, more complex modeling methods would be needed to take into account temperature differentials, material type, and insulation while estimating the effects of humidity on respiratory symptoms.

Since almost all of our participants reported IAQ issues at home, the symptoms reported by participants may be related to the issues at home rather than in the workplace. We did not have longitudinal home exposure data so this question was beyond the scope of our research. However, a study of environmental exposures among randomly sampled teachers suggested that home rather than work exposures were more highly correlated with health effects (18).

We did not collect prospective information about teachers' locations throughout the day and so are not able to assess exposures from other classrooms. Secondary classroom exposure was likely brief based on typical schedules reported by participants at enrollment. However, short-term exposures such as inhalation of copier fumes in the faculty lounge may have triggered respiratory symptoms as well.

Though we do have baseline information about certain allergens in the classroom, we do not have quantitative measures of allergen exposure in primary or secondary classrooms. Classroom allergens and irritants which are influenced by relative humidity levels may be intermediates on the pathway between relative humidity and respiratory symptoms. Thus prevention of extreme relative humidity levels would be expected to reduce classroom exposure to such allergens and irritants that could potentially trigger asthma symptoms in susceptible individuals.

Phase 1 participants were almost twice as likely as Phase 2 participants to report an asthma diagnosis at baseline, possibly due to a miscommunication that some teachers thought that the study enrollment was for asthmatic teachers only. During Phase 2 trainings, we emphasized that both asthmatic and non-asthmatic participants were needed. Thus, the distribution of Phase 2 participants was more similar to that found among other studies on teachers. Because decision to enroll may have been affected by exposure and baseline asthma status, phase of study may have been a collider on the pathway between daily RH and daily symptoms. Thus, adjustment for phase of study could have introduced bias. Despite meeting criteria for covariate inclusion for the asthma symptom models, the covariate for phase was excluded from the analysis.

Most asthma studies include smoking status as a potential confounder; however, since very few participants were current smokers, we were not able to control for this factor during analysis (Table 10.1). In addition smoking status at baseline was not expected to be related to longitudinal classroom RH levels so should not bias the relationship between daily RH and daily respiratory symptoms.

The “Free to Breathe, Free to Teach” study adds information on the association between longitudinal, classroom, RH levels (both extreme dampness and extreme dryness) and risk of teachers’ daily respiratory symptoms to the existing body of literature on indoor dampness and respiratory health effects of school building occupants. A major strength of this study was the repeated measurement of a fairly large cohort of individuals, with good subject retention. In addition, the participation of individuals at 10 different schools allowed for us to study the effects of structural factors on RH control and respiratory symptoms. Complex analysis methods were used to account for clustering by participant over time; however, the number of building clusters was not large enough to model building-level effects. The short recall period was designed to maximize outcome measurement accuracy and the data logging hygrometers provided precise measurements of the main exposure. Because both outcome and exposure data were likely missing at random and missing data patterns were related to other complete variables, we was able to impute the missing values to improve the accuracy of the estimates of association. Lastly, RH can be measured using low cost, low maintenance instruments so that this study could be replicated easily in other school populations. Humidity was also chosen because it was a more intuitive environmental parameter than some of the complex mold tests; thus, results were able to be shared with and interpreted by the school community members that they were intended to benefit.

10.4.1. Conclusion

In summary, teachers who participated in our study had a high prevalence of asthma and allergies at baseline, and a fairly high risk of asthma and cold/ allergy symptom occurrence during follow-up period. Results suggested possible unmeasured allergens in the school environment could be causing these symptoms. High and low classroom RH was associated with a higher risk of asthma symptoms among teachers in our study compared to recommended classroom RH. Increases in asthma symptoms among teachers have the potential to decrease teachers' productivity and quality of life and to disrupt classroom learning due to teacher absences. Thus maintaining classroom relative humidity within recommended levels may be an effective way to improve the classroom environment, teachers' productivity, and job-related satisfaction.

TABLE 10.1. BASELINE CHARACTERISTICS OF PARTICIPANTS (N=122)*

CHARACTERISTICS	VALUE	PHASE 1 (N=36) FALL 2010	PHASE 2 (N=86) SPRING 2011	TOTAL
Demographics		Mean (SD)	Mean (SD)	Mean (SD)
Age	(Years)	42.7 (12.2)	40.0 (11.9)	40.8 (12.0)
		N (%)	N (%)	N (%)
Gender	Male	3 (8.3)	16 (18.6)	19 (15.5)
	Female	33 (91.7)	70 (81.4)	103 (84.5)
Race***	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**	Hispanic	1 (2.8)	1 (1.2)	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)
	Other advanced degree	0 (0)	3 (3.5)	3 (2.5)
Medical/ Exposure History		N (%)	N (%)	N (%)
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)

	Pollen (spring)	12 (33.3)	28 (32.6)	40 (32.8)
	Pollen (fall)	13 (36.1)	26 (30.2)	39 (32.0)
	All pollen‡	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	Yes	36 (100.0)	82 (95.4)	118 (96.7)

* Eligible participants included full-time teachers who completed the enrollment survey and consent form at baseline. **Missing, n=6 participants; n=4 in Phase 1 and n= 2 in Phase2. ***Total % does not add up to 100 because some people chose >1 category to describe themselves. ‡ All pollen includes answers written in by participants under "Other allergens" that fit into the category of pollen allergies.

TABLE 10.2. UNADJUSTED ASSOCIATIONS BETWEEN BUILDING-RELATED FACTORS AND ASTHMA AND COLD/ ALLERGY SYMPTOMS *

		Asthma symptoms		Cold/ allergy symptoms	
Covariate	Level	N(%)	RR (95% CI)	N(%)	RR (95% CI)
Frequency of HVAC maintenance	Annually	397 (4.78)	0.19 (0.04, 0.79)	7556 (17.96)	0.95 (0.55,1.63)
	As Needed	1841 (22.16)	1.08 (0.40, 2.93)	10126 (24.07)	1.52 (0.98, 2.36)
	Quarterly	6071 (73.07)	Ref.	24382 (57.96)	Ref.
Programmed setbacks	Yes	7889 (94.95)	0.56 (0.09, 3.62)	40824 (97.05)	0.96 (0.34, 2.77)
	No	420 (5.05)	Ref.	1240 (2.95)	Ref.
Economizer	Yes	3387 (40.76)	1.09 (0.52, 2.30)	18466 (43.90)	1.28 (0.87,1.86)
	No	4922 (59.24)	Ref.	23598 (56.10)	Ref.
Building/ building wing age (years)	>40	1295 (15.59)	0.73 (0.26, 2.07)	7412 (17.62)	0.73 (0.41, 1.30)
	31-40	1865 (22.45)	2.25 (0.92, 5.52)	5314 (12.63)	1.20 (0.72, 2.01)
	11-20	2685 (32.31)	0.94 (0.38, 2.30)	15873 (37.74)	0.94 (0.59, 1.50)
	0-10	2464 (29.65)	Ref.	13465 (32.01)	Ref.

Window opened that week**	Yes	2375 (28.58)	1.20 (0.57, 2.54)	30771 (73.15)	0.97 (0.71,1.32)
	No	5934 (71.42)	Ref.	11293 (26.85)	Ref.
Average Daily Outdoor Temperature (^{o}C)**	10-unit decrease	8309 (4.85)	0.98 (0.96, 1.00)	42064 (24.54)	0.99 (0.99, 1.00)

*N=8569 person-days, missing=955 person-days for asthma symptoms and 983 person-days for cold/ allergy symptoms.
**Missing=36 person-days of observations for outdoor temperature.

TABLE 10.3. RISK RATIOS (RR) FOR THE EFFECTS OF CLASSROOM RELATIVE HUMIDITY ON RESPIRATORY SYMPTOMS AT 0 TO 2 DAY EXPOSURE LAGS*

Outcome	Relative Humidity Level	No lag, Present in School Building RR (95% CI)	One-day lag, Present in School Building RR (95% CI)	Two-day lag, Present in School Building RR (95% CI)
Asthma Symptoms**	Low (<30%)	1.09 (0.81, 1.37)	1.11 (0.81, 1.42)	1.11 (0.82, 1.41)
	Recommended (30-50%)	Ref.	Ref.	Ref.
	High (>50%)	1.09 (0.84, 1.35)	1.08 (0.81, 1.34)	1.08 (0.81, 1.35)
	Recommended (30-50%)	Ref.	Ref.	Ref.
Cold/Allergy Symptoms***	Low (<30%)	1.00 (0.89, 1.11)	1.00 (0.88, 1.11)	1.00 (0.89, 1.11)
	Recommended (30-50%)	Ref.	Ref.	Ref.
	High (>50%)	1.00 (0.90, 1.09)	1.00 (0.91, 1.09)	1.00 (0.89, 1.10)
	Recommended (30-50%)	Ref.	Ref.	Ref.

*N=8569 person-days and missing=983 person-days for cold/ allergy symptoms. The relative efficiencies for both imputed models were 0.988. **Risk ratios were estimated using a modified Poisson regression approach for correlated binary data, clustered by classroom with an autoregressive correlation matrix. The association between high RH and asthma symptoms was also adjusted for continuous outdoor temperature, based on the confounder inclusion criteria of ≥5% change in estimate. *** No potential confounders met the criteria for covariate inclusion for the models of cold/allergy symptoms.

11. DISCUSSION

11.1. SUMMARY OF KEY RESULTS AND RESTATEMENT OF AIMS

For Aim 1a, my goal was to describe proportion of classroom-days that had mean daily relative humidity (RH) within the recommended range (30-50%) in each school. Based on recommendations from committee members during the interim meeting, I chose to graphically depict the distribution of RH by date for each school. I found that most schools were not able to maintain recommended RH levels (30-50%) in their monitored classrooms for ≥50% of classroom-days.

For Aim 1b, my goal was to examine associations between classroom RH control and the following structural factors: building age, ventilation and maintenance practices, and/or previous water damage. Surprisingly, water damage in the classroom was not associated with high RH (>50%). However, having less frequently scheduled HVAC maintenance and having programmed thermostat setbacks compared to no programmed setbacks were associated with high RH. The presence of an economizer in the HVAC system was also associated with higher odds [$OR_{economizer}$=3.07 (2.04, 4.63)] of having high RH, after controlling for the effect of dehumidifying the fresh air upon intake. Low RH (>30%) was more likely in very new schools (0-10 years of age) and very old schools (>40 years of age) compared to other schools (11-40 years of age). Mechanical factors associated with increased odds of low classroom RH included having a direct-expansion (Dx) split system compared to the chilled water cooling mechanism.

For Aim 2, my goal was to estimate the associations between risk of asthma among asthmatic teachers and allergy symptoms among all teachers and daily RH average in each classroom, comparing classrooms with high (>50%) and low (<30%) RH to classrooms with recommended (30-50%) RH levels (ref.). Due to the small number of participants with asthma at baseline, I decided to estimate the associations for both allergy and asthma symptoms among all teachers. In addition, due to the inability to distinguish between cold and allergy symptoms based on the information collected, I decided to call that symptom group "cold/allergy symptoms." Among teachers present in the school building and having high classroom RH on a given day, the risk of asthma symptoms was 1.09(0.84, 1.35) times the risk of asthma among those present with recommended classroom RH. Among teachers present in the school building and having low classroom RH on a given day, the risk of asthma symptoms was 1.09 (0.81, 1.37) times the risk of asthma among those present with recommended classroom RH. The risk of asthma symptoms and cold/ allergy symptoms was increased among those present at school, independent of RH level.

11.2. STRENGTHS

This study has numerous strengths. A major strength was the repeated exposure and outcome measurement of a large cohort of individuals, with good subject retention and participant engagement. The short recall period most likely provided good outcome measurement accuracy and the data logging hygrometers provided precise measurements of the main exposure. Because both outcome and exposure data were likely missing at random and missingness could be patterned after other complete variables, the researcher was able to impute the missing values to improve the accuracy of the estimates of association.

The participation of 10 different schools allowed for the comparison of structural factors and their effects on RH control and respiratory symptoms. Complex analysis methods were used to account for clustering by participant over times. RH can be measured easily using low cost, low maintenance instruments so the exposure assessment is much more practical for school operations personnel to replicate compared to complex and costly dust samples and pollutant monitoring. Humidity was also chosen because it was an intuitive environmental parameter; thus, results were able to be shared with and interpreted by the school community members that they were intended to benefit.

Because school community members were involved in the study design and implementation from the beginning, the research questions developed were relevant to answering their concerns. In addition to trying to find practical solutions to common IAQ problems, the researcher provided trainings, toolkits, and other educational resources to school community members to help them prevent asthma triggers in their schools.

11.3. LIMITATIONS

There were also several limitations to this study. The small number of (building) clusters prevented me from being able to precisely model building level effects. Since the hygrometers were not able to be calibrated, they also may have suffered from a loss of precision over time, although the follow-up time was so short as to make this unlikely.

Sources of potential bias in the exposure measurement included the non-probability sampling of schools, which could have led to schools being chosen based on exposure. District liaisons appeared to choose schools with known or previous IAQ issues, as a way to get assistance with inspections and advice on remediation and prevention. This is supported by the high prevalence of classrooms with extreme RH in our study.

Another potential source of bias in exposure measurement was from the hygrometers falling off of the walls. This could have occurred due to a loss of adhesion of the mounting apparatus to the wall, which was more likely to occur during humid conditions. Therefore missing RH observations are potentially related to their values. When possible, I tried to place the hygrometers on surfaces rather than mounting them on the walls, to avoid this problem if I could find a suitable location. Fortunately, the proportion of missing RH observations was small compared to complete observations.

Though study retention rates were good, there were still many missing outcome observations. Missingness of symptom data was related to baseline asthma and allergy status. Non-asthmatic, non-atopic teachers were more likely to have incomplete survey data; thus, the estimates could be biased upward and away from the null if those data represent non-events.

We were able to collect cross-sectional but not longitudinal home exposure data. However, a study of environmental exposures of randomly sampled teachers suggested that home rather than work exposures were more highly correlated with health effects (18). A recent review found lower fungal concentrations in water damaged schools than water damaged homes (161). Therefore, longitudinal home exposures would be important to include on any future survey instruments.

There were also several important variables that were collected only for Phase 2 participants, including type of board writing instruments, window opening behavior, dehumidifier use, and medication use. Thus any analyses of these data must be limited to Phase 2 participants only. Some procedural aspects of data collection such as survey mode were also different between the two phases. Improvements in data collection procedures most likely led to the lower occurrences of missing observations during Phase 2; however, multiple imputation of missing data was used try to correct this potential bias.

Phase 1 participants also had several differences from Phase 2 participants. Most importantly, baseline asthma and allergy prevalence was higher among Phase 1 than Phase 2 participants, indicating possible selection bias at enrollment. Adjusting for phase could have induced bias since phase of study was potentially related to selection factors, outcome and exposure (140). Thus, phase was omitted from Aim 2 models.

11.4. PUBLIC HEALTH IMPLICATIONS

This research found that RH control is indeed difficult to maintain in most classrooms. Several recommendations were made that could improve classroom humidity control including choice of HVAC system, modification of thermostat setback procedures, and increasing the frequency of HVAC maintenance.

Teachers in our study had a high risk of cold/ allergy and asthma symptoms during our follow-up period. Though not lethal outcomes, these symptoms all can decrease teachers' productivity and quality of life, not to mention the continuity in the classroom if the teachers are absent due to these symptoms. Thus, school IAQ studies should include teachers as well as children, with the ability to look at long term health effects in teachers who maintain the same work environment for several years.

11.5. FUTURE DIRECTIONS

The "Free to Breathe, Free to Teach" study produced a rich data source offering the opportunity to explore many new study questions. Several questions of interest have come to mind. Since I measured daily asthma symptoms and also measured monthly asthma control, I would like to study the correlation between the Asthma Control Test scores and weekly asthma symptoms. Based on the studies I have read on how low RH affects viral survival and transmission, I am also interested in looking at the relationship between RH and reported influenza-like symptoms, controlling for influenza immunizations. There are other environmental variables which I would like to explore further as well, in terms of their relationship to RH, especially classroom dehumidifier use, open windows, and baseline carbon dioxide as a measure of relative classroom ventilation. Lastly, I would like to look at the effects of all of these health symptoms on teacher absenteeism.

As originally planned, I am also still interested in implementing this study throughout the state with the help of a larger research team and additional funding. To improve the quality of the statewide funding, I would randomly sample schools within interested districts and participants within schools. I would also increase the number of schools recruited and collect longitudinal data on carbon dioxide and formaldehyde levels in classrooms, since these are pollutants of extreme interest to the school operations personnel.

11.6. HUMAN SUBJECTS

This research was approved by the University of North Carolina at Chapel Hill Non-Biomedical Institutional Review Board (IRB Study # 10-1150).

APPENDIX A. WALKTHROUGH INSPECTION CHECKLIST

APPROVED - IRB. UNC-CH
FEB 11 2011

Name: ______________________________ Date Completed: _____

School: ______________________________

Building or Area: _______________ Building Age (in years): _________

Signature: ____

Instructions

1. Read the *IAQ Backgrounder* and the Background Information for this checklist from the *Tools for Schools* Kit.
2. Keep the Background Information and make a copy of the checklist for future reference.
3. Complete the Checklist.
   - Check the "yes," "no," or "not applicable" box beside each item. (Something not working properly requires further attention.)
   - Make comments in the "Notes" section as necessary.
4. Return the checklist portion of this document to the researcher.

1. GROUND LEVEL

	Yes	No	N/A
1a. Are there any current issues with ventilation units?	❑	❑	❑
1b. Is there anything blocking air intakes?	❑	❑	❑
1c. Are there any nests and/or droppings near outdoor air intakes?	❑	❑	❑
1d. Are dumpsters located away from doors, windows, and outdoor air intakes?	❑	❑	❑
1e. Are there potential sources of air contaminants near the building? (chimneys, stacks, industrial plants, exhaust from nearby buildings)	❑	❑	❑
1f. Do you have a No Idling Policy?	❑	❑	❑
1g. Do you use Integrated Pest Management?	❑	❑	❑
1h. Is there proper drainage away from the building (including roof downspouts)?	❑	❑	❑
1i. Do sprinklers spray away from the building and outdoor air intakes?	❑	❑	❑
1j. Are walk-off mats used at exterior entrances?	❑	❑	❑
1k. Are walk-off mats clean?	❑	❑	❑
1l. Is the school located near (within ≥ 1 mile of) any gas stations?	❑	❑	❑
1m. Any history of flooding?	❑	❑	❑

>> If **yes**, when? (Month, Year)___________

2. ROOF

While on the roof, consider inspecting the HVAC units (use the Ventilation Checklist*).*

	Yes	No	N/A
2a. Is the roof in good condition?	❑	❑	❑
2b. Is there evidence of water pooling?	❑	❑	❑
2c. Do ventilation units operate properly (air flows in)?	❑	❑	❑
2d. Do exhaust fans operate properly (air flows out)?	❑	❑	❑
2e. Do air intakes remain open, even at minimum setting?	❑	❑	❑
2f. Does air from plumbing stacks and exhaust outlets flow away from outdoor air intakes?	❑	❑	❑

3. BATHROOMS AND GENERAL PLUMBING

	Yes	No	N/A
3a. Do bathrooms and restrooms have operating exhaust fans?	❑	❑	❑
Proper drain trap maintenance:			
3b. Is water poured down floor drains once per week (approx. 1 quart of water)	❑	❑	❑
3c. Is water poured into sinks at least once per week (about 2 cups of water)	❑	❑	❑
3d. Are toilets flushed at least once per week	❑	❑	❑

4. GENERAL CONSIDERATIONS

	Yes	No	N/A	Location(s) of Problem
4a. Is temperature currently within acceptable range? (68-72^{o}F)............................	❑	❑	❑	______________
4b. Is relative humidity currently within acceptable range? (30-50%)....................	❑	❑	❑	______________
4c. Do all classrooms have adequate ventilation? (Check air flow, CO_2 levels)	❑	❑	❑	______________
4d. Do occupants report any odors?	❑	❑	❑	______________
4e. Are there detectable odors right now?	❑	❑	❑	______________
4f. Any signs of mold and mildew growth?...	❑	❑	❑	______________
4g. Any signs of water damage?..	❑	❑	❑	______________
4h. Any evidence of pests and obvious food sources?	❑	❑	❑	______________
4i. Any current health concerns from school occupants?	❑	❑	❑	______________
4j. Any peeling and flaking paint? (If the building was built before 1980, there could be a lead hazard)	❑	❑	❑	______________

5. MAINTENANCE SUPPLIES

5a. Is there a current maintenance log for this building?....................................	❑	❑	❑
5b. Are chemicals used only with adequate ventilation and when building is unoccupied?...	❑	❑	❑
5c. Are vents in chemical and/or trash storage areas operating properly?	❑	❑	❑

5d. What type of cleaning supplies do you use? (Brands, Toxicity, "Green" certification)

6. COMBUSTION APPLIANCES

6a. Are there any combustion gas appliances in the school?	❑	❑	❑
6b. Do you smell any combustion gas and fuel odors?...	❑	❑	❑
6c. Are there any leaks, disconnections, and deterioration?..................................	❑	❑	❑
6d. Is there soot on inside or outside of flue components?......................................	❑	❑	❑

7. OTHER

7a. Has the building been renovated?	❑	❑	❑

If yes, please list approximate date(s) of renovation_________________________________

7b. Has this building ever had a radon test?	❑	❑	❑

If yes, please list the approximate date(s) (Month, Year) ____________

7c. How many square feet per each full-time custodian? (Number)__________

7d. How many square feet per each part-time custodian? (Number)__________

7e. What type of heating, cooling and ventilation (HVAC) system is in this building? (Central unit, Multi-unit, Mixed types, Energy recovery system, type of heating)
[Choose as many as apply.] ____
....

	SF	SP	R
7f. What type of controls does the HVAC system have?	❑	❑	❑

(SF= Single room, full control; SP= Single room, partial control; R= Remotely controlled)

7g. Please list flooring type for each room, in the notes section below. (H= hard flooring; C= carpet; O= other)

8. MAINTENANCE SCHEDULE

	D	W	M	B	A	PRN	N/A
8a. How often are carpeted floors vacuumed?	❑	❑	❑	❑	❑	❑	❑
8b. How often are hard floors mopped?	❑	❑	❑	❑	❑	❑	❑
8c. How often are air filters changed?	❑	❑	❑	❑	❑	❑	❑
8d. How often is the HVAC system inspected/ maintained?	❑	❑	❑	❑	❑	❑	❑

D=Daily, W=Weekly, M=Monthly, B= Bi-Annually, A=Annually. PRN=As Needed, N/A=Not applicable

NOTES:

Room Number	Flooring Type	Notes (Temp, RH, CO_2, Issues, Best practices)

APPENDIX B. WEEKLY HEALTH DIARIES

(Phase 1: All Participants)

Free to Breathe, Free to Teach

APPROVED - IRB, UNC-CH
OCT 07 2010

<u>*Directions:*</u>

- *Please answer the following questions at the end of each work week.*
- *Return this survey to [Designated Location] on Monday.*

Days of the Week

	Directions	**M**	**Tu**	**W**	**Th**	**F**
1a. Hours at school	***For each day,*** *record the number of hours (to the nearest half hour) that you were at school. If you were not at school, write "0."*					
1b. Days Absent/ Present	***For each day,*** *write the letter that best explains your presence or absence at school.* **P=** I was present all day. **S**= I left early or was absent, because I felt sick. **N=** There was no school that day. **O**= I was gone for other reasons. (ex: Child's illness, professional days, vacation)					

*<u>Directions</u>: Please **select** "Yes," "No," or "N/A" (Not applicable) for 2a-f by placing an "X" in the box.*

2. Thinking back on this week, did you:

a) Take any allergy medications?	Yes ☐	No ☐	N/A ☐
b) Have carpool/ bus duty?	Yes ☐	No ☐	N/A ☐
c) Have recess duty?	Yes ☐	No ☐	N/A ☐
d) Open the windows in your classroom?	Yes ☐	No ☐	N/A ☐
e) Use a dehumidifier in your classroom?	Yes ☐	No ☐	N/A ☐
f) Use a humidifier in your classroom?	Yes ☐	No ☐	N/A ☐

*<u>Directions for #3-8</u>: Please **select** "Yes" or "No" for each question by placing an "X" in the box.*

Based on your answer, follow the arrows to the next set of questions.

3. Did you have any skin problems this week?

Yes ☐ ↓ No ☐ → ***Skip** to Question 4.*

Place an "X" in the box for each day(s) of the week when you experienced each symptom.

If "other," please write in the symptom in the space provided.

Symptom	Sat.	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.
Rash	☐	☐	☐	☐	☐	☐	☐
Itchy skin	☐	☐	☐	☐	☐	☐	☐
Dry skin	☐	☐	☐	☐	☐	☐	☐
Other: _________ (please specify)	☐	☐	☐	☐	☐	☐	☐

4. Did you have any breathing problems this week?

Yes ☐ ↓ No ☐ → ***Skip** to Question 5.*

Place an "X" in the box for each day(s) of the week when you experienced each symptom.

If "other," please write in the symptom in the space provided.

Symptom	**Sat.**	**Sun.**	**Mon.**	**Tues.**	**Wed.**	**Thurs.**	**Fri.**
Wheezing	☐	☐	☐	☐	☐	☐	☐
Chest pain	☐	☐	☐	☐	☐	☐	☐
Tightness in chest	☐	☐	☐	☐	☐	☐	☐
Shortness of breath	☐	☐	☐	☐	☐	☐	☐
Strange sound when breathing	☐	☐	☐	☐	☐	☐	☐
Other: _________ (please specify)	☐	☐	☐	☐	☐	☐	☐

5. Did you have any cold/ flu/ sinus/ allergy symptoms this week?

Yes ☐ ↓ No ☐ → ***Skip** to Question 6.*

Place an "X" in the box for each day(s) of the week when you experienced each symptom.

If "other," please write in the symptom in the space provided.

Symptom	Sat.	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.
Body aches (not muscle strain)	☐	☐	☐	☐	☐	☐	☐
Chills	☐	☐	☐	☐	☐	☐	☐
Stuffy Nose	☐	☐	☐	☐	☐	☐	☐
Runny Nose	☐	☐	☐	☐	☐	☐	☐
Sneezing	☐	☐	☐	☐	☐	☐	☐
Itchy eyes	☐	☐	☐	☐	☐	☐	☐
Itchy, scratchy throat	☐	☐	☐	☐	☐	☐	☐
Sore throat	☐	☐	☐	☐	☐	☐	☐
Fever (100^{o}F or more)	☐	☐	☐	☐	☐	☐	☐
Productive cough (phlegm)	☐	☐	☐	☐	☐	☐	☐
Other: _________ (please specify)	☐	☐	☐	☐	☐	☐	☐

6. Did you have any stomach or digestive problems this week?

Yes ☐ No ☐ → ***Skip** to Question 7.*

Place an "X" in the box for each day(s) of the week when you experienced each symptom.

If "other," please write in the symptom in the space provided.

Symptom	Sat.	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.
Nausea	☐	☐	☐	☐	☐	☐	☐
Stomach Pain	☐	☐	☐	☐	☐	☐	☐
Vomiting	☐	☐	☐	☐	☐	☐	☐
Diarrhea	☐	☐	☐	☐	☐	☐	☐
Other: ________ (please specify)	☐	☐	☐	☐	☐	☐	☐

7. Did you have any other health problems this week?

Yes ☐ No ☐ → ***Skip** to Question 8.*

Place an "X" in the box for each day(s) of the week when you experienced each symptom.

If "other," please write in the symptom in the space provided.

Symptom	Sat.	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.
Headache	☐	☐	☐	☐	☐	☐	☐
Fatigue/ Extremely Tired	☐	☐	☐	☐	☐	☐	☐
Dry cough	☐	☐	☐	☐	☐	☐	☐
Other: ________ (please specify)	☐	☐	☐	☐	☐	☐	☐
Other: ________ (please specify)	☐	☐	☐	☐	☐	☐	☐
Other: ________ (please specify)	☐	☐	☐	☐	☐	☐	☐

8a. If you reported any health issues, did any of these symptoms get worse in different areas of the school?

Yes ☐ No ☐ → ***Skip** to Question 9.* ← No health issues ☐

↓

b. Please explain.

____

9. a) **Did a doctor or other health professional diagnose you with asthma this week?**

Yes ☐ No ☐ → ***Skip** to Question 10.*

↓

b) Please write the date of diagnosis. (Month/Day/Year) ____________

10. *(For those with diagnosed asthma **only**.)*

During the past week, how often did you feel concerned about your asthma?

All of the time	Most of the time	Some of the time	A little of the time	None of the time	N/A
☐	☐	☐	☐	☐	☐

11. Please write any other comments below, including any new medications you took this week. (Optional):

____

____

Thank you for completing this survey!

APPENDIX C. PERMISSIONS FROM COPYRIGHT HOLDERS

QualityMetric Incorporated

NON-COMMERCIAL LICENSE AGREEMENT
Office of Grants and Scholarly Research (OGSR)

License Number: CT129166 / OP010603

Effective Date: September 13, 2010

Licensee Name: University of North Carolina

Licensee Address: University of North Carolina
Gillings School of Global Public Health
Kim Ann Gaetz
McGavran-Greenberg Hall, CB#7435
Dept of Epidemiology
Chapel Hill, NC 27599 USA

Requested Administrations: 600

Approved Use: Non-commercial academic research - grant funded by government agency or non-profit organization - Free to Breathe, Free to Teach: Indoor Air Quality in Schools and Respiratory Health of Teachers

Term: Beginning on September 17, 2010 and ending on September 16, 2011

Licensed Surveys: As indicated in Appendix B attached

Manuals: Licensee must purchase (or have purchased) from QM a copy of the manuals indicated in Appendix B attached

Royalty Fee: None, because this License is granted in support of the non-commercial Approved Use below

Administrative Fee: $250.00

Licensee accepts and agrees to the terms of this Non-Commercial License Agreement (the "Agreement") from the Office of Scholarly Grants and Research (OGSR) of QualityMetric Incorporated ("QM") as of the Effective Date.

Subject to the terms of this Agreement, including the QualityMetric Non-Commercial License Terms and Conditions attached as Appendix A: (a) QM grants to Licensee, and Licensee accepts, a non-exclusive, non-transferable, non-assignable, non-sublicensable worldwide license to use, solely for the Approved Use and during the License Term, the Licensed Surveys in the authorized Modes and Approved Languages indicated on Appendix B and to administer the Licensed Surveys only up to the Approved Administrations (and to make up to such number of exact reproductions of the Licensed Surveys necessary to support such administrations) in any combination of the specific Licensed Surveys and Approved Languages and Modes and to use any related software provided by QM and (b) Licensee agrees to pay the Administrative Fee and other applicable charges in accordance with the attached invoice.

Capitalized terms used in this Agreement and not otherwise defined herein shall have the meanings assigned to them in Appendix A. The appendices attached hereto are incorporated into and made a part of this Agreement for all purposes.

University of North Carolina
Gillings School of Global Public Health
Kim Ann Gaetz
McGavran-Greenberg Hall, CB#7435
Dept of Epidemiology
Chapel Hill, NC 27599 USA

Signature: K. A. Gaetz

Name: Kim A. Gaetz

Title: Mrs.

➢ For additional information about QM's OGSR , go to http://www.qualitymetric.com/advancing/ ≺

FileName: University of North Carolina at Chapel Hill - Kim Ann Gaetz - CT129166 OP010603 Page 1 of 4

Template - License Agreement (OGSR) - 09-2008

QUALITYMETRIC LICENSE (OGSR) - LICENSED SURVEYS AND MANUALS

Attached to and Incorporated into QM - SLA - OGSR - 09-2008.doc

Licensed Surveys and Approved Languages

ACT™ (Asthma Control Test) – Standard Recall

US - English

NO formatting or editing changes to the survey: (Very Important - Please Read)

In order to obtain licensing from Licensor no changes can be made to the survey forms. Any format and/or language changes have the potential to affect the survey data received. Therefore, to maintain the validation and integrity of the SF Health Surveys, **no language or formatting changes** are allowed. The format of the survey was scientifically engineered to facilitate accurate and unbiased data, as well as keeping the SF Health Survey in a visual format that is comprehensible to the patient/participant, including those who may be impaired and/or elderly. **You should administer the survey in the exact format you will receive it in. The only item Licensee may add is a header with patient identification and / or administration information. If you do wish to add a header please ask for a sample copy of the survey to edit and then submit this to your Account Representative for review prior to signing this License Agreement.** Other than this, Licensor can not guarantee the validity and/or reliability of data obtained from using modified surveys and we will not be able to license any modified survey form. Once the licensing process is completed, you will receive a clean set of Survey Forms in a word and pdf. file. These are the forms you will administer. Please do not use any forms you may already have access to as the ones we send you are the most current versions.

REFERENCES

1. World Health Organization. WHO Guidelines for Indoor Air Quality- Dampness and Mould. Copenhagen: WHO Regional Office for Europe, 2009.

2. Fisk WJ, Eliseeva EA, Mendell MJ. Association of residential dampness and mold with respiratory tract infections and bronchitis: a meta-analysis Environ Health. 2010;9:72. (doi: 10.1186/1476-069X-9-72).

3. Jaakkola JJ, Hwang BF, Jaakkola MS. Home dampness and molds as determinants of allergic rhinitis in childhood: a 6-year, population-based cohort study Am J Epidemiol. 2010;172(4):451-9. (doi: 10.1093/aje/kwq110).

4. Norback D, Zock JP, Plana E, et al. Lung function decline in relation to mould and dampness in the home: the longitudinal European Community Respiratory Health Survey ECRHS II Thorax. 2011;66(5):396-401. (doi: 10.1136/thx.2010.146613).

5. Daisey JM, Angell WJ, Apte MG. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. Indoor Air. 2003;13(1):53-64.

6. Patovirta RL, Husman T, Haverinen U, et al. The remediation of mold damaged school--a three-year follow-up study on teachers' health. Cent Eur J Public Health. 2004;12(1):36-42.

7. Patovirta RL, Reiman M, Husman T, et al. Mould specific IgG antibodies connected with sinusitis in teachers of mould damaged school: a two-year follow-up study. Int J Occup Med Environ Health. 2003;16(3):221-30.

8. Thomas G, Burton NC, Mueller C, et al. Comparison of work-related symptoms and visual contrast sensitivity between employees at a severely water-damaged school and a school without significant water damage. Am J Ind Med. 2012;55(9):844-54. (doi: 10.1002/ajim.22059; 10.1002/ajim.22059).

9. Sahakian NM, White SK, Park JH, et al. Identification of mold and dampness-associated respiratory morbidity in 2 schools: comparison of questionnaire survey responses to national data. J Sch Health. 2008;78(1):32-7. (doi: 10.1111/j.1746-1561.2007.00263.x).

10. Dangman KH, Bracker AL, Storey E. Work-related asthma in teachers in Connecticut: association with chronic water damage and fungal growth in schools. Conn Med. 2005;69(1):9-17.

11. Rudblad S, Andersson K, Stridh G, et al. Nasal hyperreactivity among teachers in a school with a long history of moisture problems. Am J Rhinol. 2001;15(2):135-41.

12. Ebbehoj NE, Meyer HW, Wurtz H, et al. Molds in floor dust, building-related symptoms, and lung function among male and female schoolteachers. Indoor Air. 2005;15 Suppl 10:7-16. (doi: 10.1111/j.1600-0668.2005.00352.x).

13. Santilli J, Rockwell W. Fungal contamination of elementary schools: a new environmental hazard. Ann Allergy Asthma Immunol. 2003;90(2):203-8. (doi: 10.1016/S1081-1206(10)62142-4).

14. Santilli J. Health effects of mold exposure in public schools. Curr Allergy Asthma Rep. 2002;2(6):460-7.

15. Haverinen U, Husman T, Toivola M, et al. An approach to management of critical indoor air problems in school buildings. Environ Health Perspect. 1999;107 Suppl 3:509-14.

16. Borras-Santos A, Jacobs JH, Taubel M, et al. Dampness and mould in schools and respiratory symptoms in children: the HITEA study. Occup Environ Med. 2013;70(10):681-7. (doi: 10.1136/oemed-2012-101286).

17. Haverinen-Shaughnessy U, Borras-Santos A, Turunen M, et al. Occurrence of moisture problems in schools in three countries from different climatic regions of Europe based on questionnaires and building inspections - the HITEA study. Indoor Air. 2012;22(6):457-66. (doi: 10.1111/j.1600-0668.2012.00780.x).

18. Haverinen-Shaughnessy U, Toivola M, Alm S, et al. Personal and microenvironmental concentrations of particles and microbial aerosol in relation to health symptoms among teachers. Journal of Exposure Science and Environmental Epidemiology. 2007;17(2):182-90. (doi: 10.1038/sj.jes.7500494).

19. Haverinen-Shaughnessy U, Pekkanen J, Nevalainen A, et al. Estimating effects of moisture damage repairs on students' health - a long-term intervention study. J Expo Anal Environ Epidemiol. 2004;14:S58-64. (doi: 10.1038/sj.jea.7500359).

20. Bayer CW, Hendry RJ, Crow SA, et al. The relationship between humidity and indoor air quality in schools. Indoor Air, 2002.

21. Park JH, Schleiff PL, Attfield MD, et al. Building-related respiratory symptoms can be predicted with semi-quantitative indices of exposure to dampness and mold Indoor Air. 2004;14(6):425-33. (doi: 10.1111/j.1600-0668.2004.00291.x).

22. Salo PM, Sever ML, Zeldin DC. Indoor allergens in school and day care environments. J Allergy Clin Immunol. 2009;124(2):185,92, 192.e1-9; quiz 193-4. (doi: 10.1016/j.jaci.2009.05.012).

23. Hope AP, Simon RA. Excess dampness and mold growth in homes: an evidence-based review of the aeroirritant effect and its potential causes. Allergy Asthma Proc. 2007;28(3):262-70.

24. Karvala K, Toskala E, Luukkonen R, et al. New-onset adult asthma in relation to damp and moldy workplaces. Int Arch Occup Environ Health. 2010;83(8):855-65. (doi: 10.1007/s00420-010-0507-5).

25. Kolstad HA, Brauer C, Iversen M, et al. Do indoor molds in nonindustrial environments threaten workers' health? A review of the epidemiologic evidence. Epidemiol Rev. 2002;24(2):203-17.

26. Mold remediation in schools and commercial buildings [electronic resource] Washington, DC, U.S. Environmental Protection Agency, Office of Air and Radiation, Indoor Environments Division, 2001.

27. Safe and healthy school environments. Frumkin H, editor. Oxford ;New York: Oxford University Press, 2006.

28. Vesper S, Parkhurst S. Evaluating ERMI. The Synergist. 2009.

29. Jones R, Recer GM, Hwang SA, et al. Association between indoor mold and asthma among children in Buffalo, New York. Indoor Air. 2011;21(2):156-64. (doi: 10.1111/j.1600-0668.2010.00692.x; 10.1111/j.1600-0668.2010.00692.x).

30. Cai GH, Hashim JH, Hashim Z, et al. Fungal DNA, allergens, mycotoxins and associations with asthmatic symptoms among pupils in schools from Johor Bahru, Malaysia. Pediatr Allergy Immunol. 2011;22(3):290-7. (doi: 10.1111/j.1399-3038.2010.01127.x; 10.1111/j.1399-3038.2010.01127.x).

31. Parkhurst S. Beyond ERMI. The Synergist. 2009:36-8.

32. Horner WE, Barnes C, Codina R, et al. Guide for interpreting reports from inspections/investigations of indoor mold. J Allergy Clin Immunol. 2008;121(3):592-7. (doi: 10.1016/j.jaci.2007.11.020).

33. Kildeso J, Wurtz H, Nielsen K, et al. Determination of fungal spore release from wet building materials. Indoor Air. 2003;13(2):148-55. (doi: 10.1034/j.1600-0668.2003.00172.x).

34. Johansson P, Ekstrand-Tobin A, Svensson T, et al. Laboratory study to determine the critical moisture level for mould growth on building materials. Int Biodeterior Biodegrad. 2012;73:23-32. (doi: 10.1016/j.ibiod.2012.05.014).

35. Johansson P, Svensson T, Ekstrand-Tobin A. Validation of critical moisture conditions for mould growth on building materials. Build Environ. 2013;62:201-9. (doi: 10.1016/j.buildenv.2013.01.012).

36. Johansson P, Bok G, Ekstrand-Tobin A. The effect of cyclic moisture and temperature on mould growth on wood compared to steady state conditions. Build Environ. 2013;65:178-84. (doi: 10.1016/j.buildenv.2013.04.004).

37. United States Environmental Protection Agency. Mold Remediation in Schools and Commercial Buildings. 2008.

38. Assessing Water Damage to Gypsum Board. Gypsum Association, editor. , 2006.

39. Chao HJ, Schwartz J, Milton DK, et al. Populations and determinants of airborne fungi in large office buildings. Environ Health Perspect. 2002;110(8):777-82.

40. ARLIAN L. Humidity as a Factor Regulating Feeding and Water-Balance of House Dust Mites Dermatophagoides-Farinae and Dermatophagoides-Pteronyssinus (Acari Pyroglyphidae). J Med Entomol. 1978;14(4):484-8.

41. Arlian LG, Confer PD, Rapp CM, et al. Population dynamics of the house dust mites Dermatophagoides farinae, D-pteronyssinus, and Euroglyphus maynei (Acari : Pyroglyphidae) at specific relative humidities. J Med Entomol. 1998;35(1):46-53.

42. Foarde K, Berry M. Comparison of biocontaminant levels associated with hard vs. carpet floors in nonproblem schools: results of a year long study. J Expo Anal Environ Epidemiol. 2004;14 Suppl 1:S41-8. (doi: 10.1038/sj.jea.7500357).

43. Singh M, Jaiswal N. Dehumidifiers for chronic asthma. Cochrane Database Syst Rev. 2013;6:CD003563. (doi: 10.1002/14651858.CD003563.pub2; 10.1002/14651858.CD003563.pub2).

44. Cho SJ, Ramachandran G, Grengs J, et al. Longitudinal evaluation of allergen and culturable fungal concentrations in inner-city households. J Occup Environ Hyg. 2008;5(2):107-18. (doi: 10.1080/15459620701827049).

45. Smedje G, Norback D. Irritants and allergens at school in relation to furnishings and cleaning. Indoor Air. 2001;11(2):127-33.

46. Oeder S, Dietrich S, Weichenmeier I, et al. Toxicity and elemental composition of particulate matter from outdoor and indoor air of elementary schools in Munich, Germany. Indoor Air. 2012;22(2):148-58. (doi: 10.1111/j.1600-0668.2011.00743.x; 10.1111/j.1600-0668.2011.00743.x).

47. Global Initiative for Asthma (GINA). From the Global Strategy for Asthma Management and Prevention. 2011.

48. Batterman S, Du L, Mentz G, et al. Particulate matter concentrations in residences: An intervention study evaluating stand-alone filters and air conditioners. Indoor Air. 2012;22(3):235-52. (doi: 10.1111/j.1600-0668.2011.00761.x; 10.1111/j.1600-0668.2011.00761.x).

49. Matthews TG, Fung KW, Tromberg BJ, et al. Impact of indoor environmental parameters on formaldehyde concentrations in unoccupied research houses. J Air Pollut Control Assoc. 1986;36(11):1244-9.

50. Syrett P, Youssef C, Farrah K, et al. Healthy Environments: A Compilation of Substances Linked to Asthma. New York: Perkins+Will, 2012.

51. Indoor Air Quality: Tools for Schools: Action Kit. United States. Environmental Protection Agency., editor. [Washington, DC] : EPA : AFT ;[Reston, VA] : ASBO ;[Washington, DC] : CAPE : NEA ;[Chicago, IL] : PTA ;[New York, N.Y.] : American Lung Association, 1995.

52. The Children's Health Act. 2006.

53. Wolkoff P, Kjaergaard SK. The dichotomy of relative humidity on indoor air quality. Environ Int. 2007;33(6):850-7. (doi: 10.1016/j.envint.2007.04.004).

54. Bakke JV, Norback D, Wieslander G, et al. Symptoms, complaints, ocular and nasal physiological signs in university staff in relation to indoor environment - temperature and gender interactions. Indoor Air. 2008;18(2):131-43. (doi: 10.1111/j.1600-0668.2007.00515.x [doi]).

55. Lowen AC, Mubareka S, Steel J, et al. Influenza virus transmission is dependent on relative humidity and temperature. PLoS Pathog. 2007;3(10):1470-6. (doi: 10.1371/journal.ppat.0030151).

56. Shaman J, Kohn M. Absolute humidity modulates influenza survival, transmission, and seasonality. Proc Natl Acad Sci U S A. 2009;106(9):3243-8. (doi: 10.1073/pnas.0806852106).

57. Shaman J, Pitzer VE, Viboud C, et al. Absolute Humidity and the Seasonal Onset of Influenza in the Continental United States. PLoS Biol. 2010;8(2):. Epub 2010 Feb 23 doi:10.1371/journal.pbio.1000316. (doi: 10.1371/journal.pbio.1000316).

58. Casanova LM, Jeon S, Rutala WA, et al. Effects of air temperature and relative humidity on coronavirus survival on surfaces. Appl Environ Microbiol. 2010;76(9):2712-7. (doi: 10.1128/AEM.02291-09).

59. Sun Y, Wang Z, Zhang Y, et al. In China, students in crowded dormitories with a low ventilation rate have more common colds: evidence for airborne transmission. PLoS One. 2011;6(11):e27140. (doi: 10.1371/journal.pone.0027140).

60. JLC Field Guide to Residential Construction: A Manual of Best Practice. Vol. 2 ed. Williston: Journal of Light Construction, Hanley Wood LLC, 2006.

61. Cooper G. Air-conditioning America : engineers and the controlled environment, 1900-1960. Baltimore: Johns Hopkins University Press, 1998.

62. Brumbaugh JE. Audel HVAC fundamentals. Brumbaugh JE, editor. Indianapolis, Ind.: Wiley Pub, 2004.

63. Bhatia A. Air Conditioning Psychrometrics. New York: Continuing Education and Development, Inc. Accessed 2014.

64. Persily A. Myths about building envelopes. ASHRAE Journal. 1999;41(3):39-47.

65. The Water Cycle: Condensation , United States Geological Survey, 2012.

66. Guidry VT, Margolis LH. Unequal respiratory health risk: using GIS to explore hurricane-related flooding of schools in Eastern North Carolina. Environ Res. 2005;98(3):383-9. (doi: 10.1016/j.envres.2004.10.007).

67. Funds under Control of the State Board of Education. 1983.

68. Engvall K, Wickman P, Norback D. Sick building syndrome and perceived indoor environment in relation to energy saving by reduced ventilation flow during heating season: a 1 year intervention study in dwellings. Indoor Air. 2005;15(2):120-6. (doi: 10.1111/j.1600-0668.2004.00325.x).

69. Nicholson PJ, Cullinan P, Burge PS, et al. Occupational asthma: Prevention, identification & management: Systematic review & recommendations. London: British Occupational Health Research Foundation. 2010.

70. Selgrade MK, Lemanske RF,Jr, Gilmour MI, et al. Induction of asthma and the environment: what we know and need to know. Environ Health Perspect. 2006;114(4):615-9.

71. Von Behren J, Lipsett M, Horn-Ross PL, et al. Obesity, waist size and prevalence of current asthma in the California Teachers Study cohort. Thorax. 2009;64(10):889-93. (doi: 10.1136/thx.2009.114579).

72. Sotir M, Yeatts K, Shy C. Presence of asthma risk factors and environmental exposures related to upper respiratory infection-triggered wheezing in middle school-age children Environ Health Perspect. 2003;111(4):657-62.

73. Diette GB, Hansel NN, Buckley TJ, et al. Home indoor pollutant exposures among inner-city children with and without asthma. Environ Health Perspect. 2007;115(11):1665-9. (doi: 10.1289/ehp.10088).

74. Brooks C, Pearce N, Douwes J. The hygiene hypothesis in allergy and asthma: an update. Curr Opin Allergy Clin Immunol. 2012. (doi: 10.1097/ACI.0b013e32835ad0d2).

75. Elliott L, Yeatts K, Loomis D. Ecological associations between asthma prevalence and potential exposure to farming. Eur Respir J. 2004;24(6):938-41. (doi: 10.1183/09031936.04.00006404).

76. Fuhlbrigge A, Reed ML, Stempel DA, et al. The status of asthma control in the U.S. adult population. Allergy Asthma Proc. 2009;30(5):529-33. (doi: 10.2500/aap.2009.30.3276).

77. Behavioral Risk Factor Surveillance System (BRFSS) Calendar Year 2010 Results Raleigh, North Carolina State Center for Health Statistics, 2011.

78. Vesper S, McKinstry C, Ashley P, et al. Quantitative PCR analysis of molds in the dust from homes of asthmatic children in North Carolina J Environ Monit. 2007;9(8):826-30. (doi: 10.1039/b704359g).

79. Henneberger PK, Mirabelli MC, Kogevinas M, et al. The occupational contribution to severe exacerbation of asthma Eur Respir J. 2010. (doi: 10.1183/09031936.00135109).

80. Quinn K, Kaufman JS, Siddiqi A, et al. Parent perceptions of neighborhood stressors are associated with general health and child respiratory health among low-income, urban families J Asthma. 2010;47(3):281-9. (doi: 10.3109/02770901003605324).

81. Quinn K, Kaufman JS, Siddiqi A, et al. Stress and the city: housing stressors are associated with respiratory health among low socioeconomic status Chicago children. J Urban Health. 2010;87(4):688-702. (doi: 10.1007/s11524-010-9465-1; 10.1007/s11524-010-9465-1).

82. Jepson E, Forrest S. Individual contributory factors in teacher stress: The role of achievement striving and occupational commitment. Br J Educ Psychol. 2006;76(1):183-97. (doi: 10.1348/000709905X37299).

83. Miller R. Tales of Teacher Absence: New Research Yields Patterns that Speak to Policymakers. 2008.

84. Buckley JP, Richardson DB. Seasonal modification of the association between temperature and adult emergency department visits for asthma: a case-crossover study. Environ Health. 2012;11:55,069X-11-55. (doi: 10.1186/1476-069X-11-55; 10.1186/1476-069X-11-55).

85. Yeh KW, Chang CJ, Huang JL. The association of seasonal variations of asthma hospitalization with air pollution among children in Taiwan. Asian Pac J Allergy Immunol. 2011;29(1):34-41.

86. May L, Carim M, Yadav K. Adult asthma exacerbations and environmental triggers: a retrospective review of ED visits using an electronic medical record Am J Emerg Med. 2010. (doi: 10.1016/j.ajem.2010.06.034).

87. Hanna AF, Yeatts KB, Xiu A, et al. Associations between ozone and morbidity using the Spatial Synoptic Classification system. Environ Health. 2011;10:49. (doi: 10.1186/1476-069X-10-49).

88. Cakmak S, Dales RE, Coates F. Does air pollution increase the effect of aeroallergens on hospitalization for asthma? J Allergy Clin Immunol. 2011. (doi: 10.1016/j.jaci.2011.09.025).

89. Pascual M. Epigenetic approaches to allergy research electronic resource]. Roa S, editor. New York, NY: Springer, 2013.

90. Rottem M, Gershwin ME, Shoenfeld Y. Allergic disease and autoimmune effectors pathways. Dev Immunol. 2002;9(3):161-7.

91. Yeatts K, Sly P, Shore S, et al. A brief targeted review of susceptibility factors, environmental exposures, asthma incidence, and recommendations for future asthma incidence research. Environ Health Perspect. 2006;114(4):634-40.

92. Mireku N, Wang Y, Ager J, et al. Changes in weather and the effects on pediatric asthma exacerbations Ann Allergy Asthma Immunol. 2009;103(3):220-4. (doi: 10.1016/S1081-1206(10)60185-8).

93. Sattar SA, Karim YG, Springthorpe VS, et al. Survival of human rhinovirus type 14 dried onto nonporous inanimate surfaces: effect of relative humidity and suspending medium. Can J Microbiol. 1987;33(9):802-6.

94. Karim YG, Ijaz MK, Sattar SA, et al. Effect of relative humidity on the airborne survival of rhinovirus-14. Can J Microbiol. 1985;31(11):1058-61.

95. Sahlberg B, Mi YH, Norback D. Indoor environment in dwellings, asthma, allergies, and sick building syndrome in the Swedish population: a longitudinal cohort study from 1989 to 1997. Int Arch Occup Environ Health. 2009;82(10):1211-8. (doi: 10.1007/s00420-009-0444-3).

96. Mendell MJ, Cozen M, Lei-Gomez Q, et al. Indicators of moisture and ventilation system contamination in U.S. office buildings as risk factors for respiratory and mucous membrane symptoms: analyses of the EPA BASE data J Occup Environ Hyg. 2006;3(5):225-33. (doi: 10.1080/15459620600628589).

97. Patovirta RL, Meklin T, Nevalainen A, et al. Effects of mould remediation on school teachers' health. Int J Environ Health Res. 2004;14(6):415-27. (doi: 10.1080/09603120400012876).

98. Pongracic JA, O'Connor GT, Muilenberg ML, et al. Differential effects of outdoor versus indoor fungal spores on asthma morbidity in inner-city children. J Allergy Clin Immunol. 2010;125(3):593-9. (doi: 10.1016/j.jaci.2009.10.036).

99. Thorn A, Lewne M, Belin L. Allergic alveolitis in a school environment. Scand J Work Environ Health. 1996;22(4):311-4.

100. Committee on Environmental Health, American Academy of Pediatrics, Kim JJ, Mazur LJ. Spectrum of noninfectious health effects from molds. Pediatrics. 2006;118(6):2582-6. (doi: 10.1542/peds.2006-2828).

101. Khary J. Cook e. Employment & Earnings Online. Khary J. Cook e, editor. Washington, DC: U.S. Bureau of Labor Statistics, 2011.

102. Meng YY, Babey SH, Hastert TA, et al. Uncontrolled asthma means missed work and school, emergency department visits for many Californians. Policy Brief UCLA Cent Health Policy Res. 2008;(PB2008-2)(PB2008-2):1-8.

103. McHugh MK, Symanski E, Pompeii LA, et al. Prevalence of asthma by industry and occupation in the U.S. working population. Am J Ind Med. 2010;53(5):463-75. (doi: 10.1002/ajim.20800).

104. Whelan EA, Lawson CC, Grajewski B, et al. Prevalence of respiratory symptoms among female flight attendants and teachers Occup Environ Med. 2003;60(12):929-34.

105. Eng A, 'T Mannetje A, Douwes J, et al. The New Zealand workforce survey II: occupational risk factors for asthma. Ann Occup Hyg. 2010;54(2):154-64. (doi: 10.1093/annhyg/mep098; 10.1093/annhyg/mep098).

106. Mazurek JM, Filios M, Willis R, et al. Work-related asthma in the educational services industry: California, Massachusetts, Michigan, and New Jersey, 1993-2000. Am J Ind Med. 2008;51(1):47-59. (doi: 10.1002/ajim.20539).

107. Fletcher AM, London MA, Gelberg KH, et al. Characteristics of patients with work-related asthma seen in the New York State Occupational Health Clinics. J Occup Environ Med. 2006;48(11):1203-11. (doi: 10.1097/01.jom.0000245920.87676.7b).

108. Mirabelli MC, Wing S. Proximity to pulp and paper mills and wheezing symptoms among adolescents in North Carolina. Environ Res. 2006;102(1):96-100. (doi: 10.1016/j.envres.2005.12.004).

109. Mirabelli MC, Wing S, Marshall SW, et al. Race, poverty, and potential exposure of middle-school students to air emissions from confined swine feeding operations. Environ Health Perspect. 2006;114(4):591-6.

110. Mirabelli MC, Wing S, Marshall SW, et al. Asthma symptoms among adolescents who attend public schools that are located near confined swine feeding operations. Pediatrics. 2006;118(1):e66-75. (doi: 10.1542/peds.2005-2812).

111. SAS Institute. SAS. Cary, 2011.

112. The Research Methods Knowledge Base, 2nd Edition, 2006.

113. "Relative Humidity and Dewpoint from Wet-bulb" El Paso, National Weather Service, 2009.

114. State Climate Office of North Carolina. CRONOS [internet database]. Raleigh: NC State University, 2010.

115. 2008 Behavioral Risk Factor and Surveillance System (BRFSS) Asthma Call-back Questionnaire for Adults Atlanta, Centers for Disease Control and Prevention, 2009. (http://www.cdc.gov.libproxy.lib.unc.edu/asthma/survey/brfss.html).

116. American Fact Finder, 2006-2010, 2011.

117. Wing S, Wolf S. Intensive livestock operations, health, and quality of life among eastern North Carolina residents. Environ Health Perspect. 2000;108(3):233-8.

118. Juniper EF, O'Byrne PM, Ferrie PJ, et al. Measuring asthma control. Clinic questionnaire or daily diary? Am J Respir Crit Care Med. 2000;162(4 Pt 1):1330-4.

119. Schatz M, Sorkness CA, Li JT, et al. Asthma Control Test: reliability, validity, and responsiveness in patients not previously followed by asthma specialists J Allergy Clin Immunol. 2006;117(3):549-56. (doi: 10.1016/j.jaci.2006.01.011).

120. Nathan RA, Sorkness CA, Kosinski M, et al. Development of the asthma control test: a survey for assessing asthma control J Allergy Clin Immunol. 2004;113(1):59-65. (doi: 10.1016/j.jaci.2003.09.008).

121. Juniper EF, Bousquet J, Abetz L, et al. Identifying 'well-controlled' and 'not well-controlled' asthma using the Asthma Control Questionnaire Respir Med. 2006;100(4):616-21. (doi: 10.1016/j.rmed.2005.08.012).

122. Juniper EF, O'Byrne PM, Guyatt GH, et al. Development and validation of a questionnaire to measure asthma control Eur Respir J. 1999;14(4):902-7.

123. Chang CH, Sharp LK, Kimmel LG, et al. A 6-item brief measure for assessing perceived control of asthma in culturally diverse patients Ann Allergy Asthma Immunol. 2007;99(2):130-5. (doi: 10.1016/S1081-1206(10)60636-9).

124. Vollmer WM, Markson LE, O'Connor E, et al. Association of asthma control with health care utilization and quality of life Am J Respir Crit Care Med. 1999;160(5 Pt 1):1647-52.

125. Juniper EF, Guyatt GH, Epstein RS, et al. Evaluation of impairment of health related quality of life in asthma: development of a questionnaire for use in clinical trials Thorax. 1992;47(2):76-83.

126. Juniper EF, Norman GR, Cox FM, et al. Comparison of the standard gamble, rating scale, AQLQ and SF-36 for measuring quality of life in asthma Eur Respir J. 2001;18(1):38-44.

127. QualityMetric Incorporated. Asthma Control Test™ , 2002.

128. Juniper EF, Svensson K, Mork AC, et al. Measurement properties and interpretation of three shortened versions of the asthma control questionnaire Respir Med. 2005;99(5):553-8. (doi: 10.1016/j.rmed.2004.10.008).

129. Jia CE, Zhang HP, Lv Y, et al. The Asthma Control Test and Asthma Control Questionnaire for assessing asthma control: Systematic review and meta-analysis. J Allergy Clin Immunol. 2013;131(3):695-703. (doi: 10.1016/j.jaci.2012.08.023; 10.1016/j.jaci.2012.08.023).

130. Qualtrics Labs I. Qualtrics Labs, Inc. Provo, Utah, 2011.

131. O'Neill MS. Helping schoolchildren with asthma breathe easier: partnerships in community-based environmental health education. Environ Health Perspect. 1996;104(5):464-6.

132. Random.org , Accessed 2012.

133. North Carolina Public Schools Statistical Profile , 2011.

134. Equinoxes, Solstices, Perihelion, and Aphelion, 2000-2020 Stennis Space Center, Naval Meteorology and Oceanography Command, 2001.

135. Singer JD. Applied longitudinal data analysis : modeling change and event occurrence. Willett JB, editor. Oxford ;New York: Oxford University Press, 2003.

136. Cooley P, Ganapathi L, Ghneim G, et al. Using influenza-like illness data to reconstruct an influenza outbreak. Math Comput Model. 2008;48(5–6):929-39. (doi: http://dx.doi.org/10.1016/j.mcm.2007.11.016).

137. Brumbaugh JE, author. AudelHVAC Fundamentals electronic resource]: Volume 2: Heating System Components, Gas and Oil Burners, and Automatic Controls. Audel Imprint] Nov. 2004 Hoboken: John Wiley & Sons, 2004.

138. Brager GS, de Dear R. Climate, comfort, & natural ventilation: a new adaptive comfort standard for ASHRAE standard 55, 2001.

139. Textor J, Hardt J, Knuppel S. DAGitty: a graphical tool for analyzing causal diagrams. Epidemiology. 2011;22(5):745. (doi: 10.1097/EDE.0b013e318225c2be; 10.1097/EDE.0b013e318225c2be).

140. Rothman KJ. Modern epidemiology. Lash TL, editor. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins, 2008.

141. Beunckens C, Sotto C, Molenberghs G. A simulation study comparing weighted estimating equations with multiple imputation based estimating equations for longitudinal binary data. Comput Stat Data Anal. 2008;52(3):1533-48. (doi: 10.1016/j.csda.2007.04.020).

142. Schwartz T, Chen Q, Duan N. Studying missing data patterns using a SAS macro. Cary: SAS Institute, 2011.

143. van Buuren S. Multiple imputation of discrete and continuous data by fully conditional specification. Stat Methods Med Res. 2007;16(3):219-42. (doi: 10.1177/0962280206074463).

144. Zou G. A modified poisson regression approach to prospective studies with binary data. Am J Epidemiol. 2004;159(7):702-6.

145. Zou G, Donner A. Extension of the modified Poisson regression model to prospective studies with correlated binary data. Stat Methods Med Res. 2013;22(6):661-70. (doi: 10.1177/0962280211427759; 10.1177/0962280211427759).

146. Pan W. Akaike's information criterion in generalized estimating equations. Biometrics. 2001;57(1):120-5.

147. The 2011 HHS Poverty Guidelines: One Version of the [U.S.] Federal Poverty Measure , 2011.

148. Brumbaugh JE. Audel HVAC fundamentals. Volume 3, Air-conditioning, heat pumps, and distribution systems electronic resource]. Ebook Library., editor. Indianapolis, IN: Wiley Pub.. Inc, 2004.

149. American Society of Heating, Refrigerating,and Air. Thermal environmental conditions for human occupancy. American National Standards Institute., editor. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2004.

150. Sun Y, Zhang Y, Bao L, et al. Ventilation and dampness in dorms and their associations with allergy among college students in China: a case-control study. Indoor Air. 2011;21(4):277-83. (doi: 10.1111/j.1600-0668.2010.00699.x; 10.1111/j.1600-0668.2010.00699.x).

151. Norback D, Nordstrom K. Sick building syndrome in relation to air exchange rate, CO(2), room temperature and relative air humidity in university computer classrooms: an experimental study. Int Arch Occup Environ Health. 2008;82(1):21-30. (doi: 10.1007/s00420-008-0301-9).

152. State Climate Office of North Carolina. CRONOS [internet database]. Raleigh: NC State University, 2011.

153. Mirabelli MC. Email Correspondance, 2009.

154. Odom JD, Scott R, DuBose GH. The Hidden Risks of Green Building: Avoiding Mold and Moisture Problems. NCARB Mini-Monograph. 2007.

155. Neal JS, Arlian LG, Vyszenski-Moher DL, et al. Population growth of dust mites exposed to fluctuating relative humidity. J Allergy Clin Immunol. 1998;101(1):S24.

156. Arlian LG, Neal JS, Vyszenski-Moher DL. Reducing relative humidity to control the house dust mite Dermatophagoides farinae. J Allergy Clin Immunol. 1999;104(4):852-6.

157. Institute of Medicine (US) Committee on Damp Indoor Spaces,and Health. Damp indoor spaces and health. Washington, D.C.: National Academies Press, 2004.

158. Sato M, Fukayo S, Yano E. Adverse environmental health effects of ultra-low relative humidity indoor air. J Occup Health. 2003;45(2):133-6.

159. National Heart, Lung, and Blood Institute. Expert Panel Report 3:Guidelines for the Diagnosis and Management of Asthma. National Institutes of Health, editor. Bethesda: U.S. Department of Health and Human Services, 2007.

160. Simpson WT. Equilibrium moisture content of wood in outdoor locations in the United States and worldwide. Madison: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 1998.

161. Sauni R, Uitti J, Jauhiainen M, et al. Remediating buildings damaged by dampness and mould for preventing or reducing respiratory tract symptoms, infections and asthma. Cochrane Database Syst Rev. 2011;9:CD007897. (doi: 10.1002/14651858.CD007897.pub2).