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Workplace indoor environmental quality and asthma-related outcomes in healthcare workers

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Abstract

Background: Asthma-related health outcomes are known to be associated with indoor moisture and renovations. The objective of this study was to estimate the frequency of these indoor environmental quality (IEQ) factors in healthcare facilities and their association with asthma-related outcomes among workers.

Methods: New York City healthcare workers (n = 2030) were surveyed regarding asthma-related symptoms, and moisture and renovation factors at work and at home during the last 12 months. Questions for workplace moisture addressed water damage (WD), mold growth (MG), and mold odor (MO), while for renovations they addressed painting (P), floor renovations (FR), and wall renovations (WR). Regression models were fit to examine associations between work and home IEQ factors and multiple asthma-related outcomes.

Results: Reports of any moisture (n = 728, 36%) and renovations (n = 1412, 70%) at work were common. Workplace risk factors for asthma-related outcomes included the moisture categories of WD by itself, WD with MO (without MG), and WD with MG and MO, and the renovation category with the three factors P, FR, and WR. Reports of home IEQ factors were less frequent and less likely to be associated with health outcomes. Data analyses suggested that MG and/or MO

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AUTHOR CONTRIBUTIONS
PKH and MAV conceptualized and designed the study with input from ABS, RFL, MLS, and XL, MJH, PKH, MAV, and MLS planned and managed the data collection. PKH, MAV, and FCS planned the data analysis, and SMR, FCS, and XL implemented the analysis. PKH, MAV, FCS, and SMR interpreted the results. SMR and PKH drafted the original manuscript, and all authors contributed to multiple revisions to yield the final manuscript.

CONFLICTS OF INTEREST
The authors declare that there are no conflicts of interest.

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ETHICS APPROVAL AND INFORMED CONSENT
This study was reviewed and approved by the NIOSH Institutional Review Board. Informed consent was given before an invitee participated in the study.

DISCLAIMER
The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

SUPPORTING INFORMATION
Additional supporting information may be found online in the Supporting Information section.

at work and at home had a synergistic effect on the additive scale with a symptom-based algorithm for bronchial hyperresponsiveness.

Conclusions: The current study determined that moisture and renovation factors are common in healthcare facilities, potentially putting workers at risk for asthma-related outcomes. More research is needed to confirm these results, especially prospective studies.

Keywords

healthcare; indoor environmental quality; mold; renovations; work-related asthma

1 INTRODUCTION

Asthma is a common respiratory disease, affecting approximately 6.8% of the United States' working-age population.[1] Excessive moisture and mold at work are known to lead to exposures that contribute to asthma onset and exacerbation.[2,3] Work-related asthma (WRA) is an umbrella term that encompasses two categories: occupational asthma (OA) and work-exacerbated asthma (WEA). OA is defined as asthma that is caused by workplace exposures, while WEA is defined as a worsening of existing asthma due to the workplace environment. On the basis of the statements from the American Thoracic Society, 16% of incident asthma among adults is attributable to the workplace, while WEA has a 21.5% prevalence among adults with asthma.[4,5] WRA can be costly. Follow-up studies of OA cases reported prolonged unemployment rates of 14% to 69% and rates of lost income ranging from 44% to 72%, with similar results for WEA cases.[6]

Workers in the healthcare industry have been shown to have a higher risk for developing asthma and asthma-related symptoms, such as wheeze and shortness of breath (SOB), than workers in other industries.[7-9] This heightened risk can be attributed to many of the tasks performed by healthcare workers, including cleaning/sterilizing medical instruments, the use of powdered latex gloves, and administering aerosolized medication, among others.[10] In the mid-1990s, surveillance data gathered from four states showed that 15.6% of WRA cases came from the healthcare industry, despite representing only 8.0% of the total workforce in those states.[7] An analysis of data from the more recent 2009-2014 National Health Interview Survey showed that asthma prevalence was higher in the healthcare and social assistance industry (8.8%) compared with any other industry.[11]

The development of respiratory problems, such as asthma and wheezing, has been shown to be associated with damp indoor environments. In 2004, the Institute of Medicine (IOM) performed a comprehensive review of the literature examining moisture and mold in buildings and health effects. This report found sufficient evidence for the association of wheeze, other asthma symptoms, and exacerbation of asthma with areas of excessive moisture and mold.[12] Reviews conducted subsequent to the 2004 IOM review indicate the evidence has strengthened. These reviews, conducted by the World Health Organization in 2009[2] and later by Mendell et al in 2011,[3] found sufficient evidence for the association of wheeze, the development of asthma, and current asthma with damp indoor environments.[13] Many studies included in the reviews used visual or olfactory observations by either study participants or investigators to identify indoor moisture problems. A 2017 review summarized findings for a dose-response relationship of observational indicators of residential dampness and mold with respiratory health effects.[14]

Many prior studies focusing on asthma in healthcare workers have examined whether the risk is higher for specific occupations or for those who perform certain tasks. Fewer studies have estimated the association between asthma and workplace indoor environmental quality (IEQ) not specific to occupation or task in healthcare.[15,16] The current study aims to examine the frequency of observational reports by healthcare workers of water damage (WD), mold, and renovation activities at work and at home, and the association of these factors with asthma-related outcomes.

2 MATERIALS AND METHODS

2.1 Study population and data collection

This study was reviewed and approved by the National Institute for Occupational Safety and Health (NIOSH) Institutional Review Board. An invitation to participate and a description of the study's purpose was mailed to invitees and informed consent was given before an invitee participated in the study.

The enlistment of participants is explained in greater detail in a previous publication.[17] Briefly, invitees were all members of the Service Employees International Union Local 1199 in New York City and worked in one of nine target healthcare occupations: nursing assistants, central supply workers, dental assistants, environmental service workers, laboratory technicians, licensed practical nurses, operating room technicians, registered nurses, and respiratory therapists or technicians. In February 2014, numerous mailings and telephone calls were initiated to encourage invitees to complete the main survey questionnaire, after which nonresponders were telephoned and asked to complete a short nonresponder questionnaire.

2.2 Survey instruments

The questionnaire addressed a wide range of topics, including demographic characteristics, occupational history, tasks performed, asthma-related outcomes, and indoor environmental factors both at work and at home. Many questions came from standardized questionnaires,[18-20] while others came from a prior study of Texas healthcare workers.[21] Both English and Spanish versions of the questionnaire were developed for use in telephone interviews, while the online version was limited to English.

2.3 Inverse probability weights for selection and nonparticipation

The 2030 participants who completed the survey questionnaire represented 13.3% of the effective sample size (ie, 15 213 invitees known or presumed to be eligible), and 22.5% of the 9009 with whom at least some telephone contact was made. Over 250 healthcare facilities were represented in this study. To account for both selection and nonparticipation bias, weights based on inverse probability were developed and included in all regression models. These final weights were the product of three separate interim weights. The first interim weight accounted for potential selection bias; the other two addressed potential nonparticipation bias. Full details of how these weights were calculated can be found in an earlier work.[17]

2.4 Dependent variables

Participants with self-reported physician-diagnosed asthma were categorized as having current asthma if they met at least one of the following criteria: an attack of asthma in the last 12 months, overnight hospitalization due to asthma in the last 12 months, medication use for asthma in the last 12 months, urgent care/treatment for asthma in the last 12 months, or having an asthma score ≥ 1. These criteria were derived from prior definitions of current asthma based on the European Community Respiratory Health Survey (ECRHS).[22]

Individuals with asthma-related symptoms (including those without an asthma diagnosis) were identified by any of three mechanisms: a validated asthma score, an algorithm for bronchial hyperresponsiveness (BHR)-related symptoms and asthma health clusters. The asthma score was developed by ECRHS researchers and is calculated as the sum of the positive answers to five questions regarding breathlessness while wheezing, waking with a feeling of chest tightness, attack of SOB either at rest or after exercise, and waking due to an attack of SOB, all during the last 12 months.[18] This score has been validated against known asthma indicators and has been a useful tool in many other studies.[18,23]

We used the BHR symptom algorithm developed by Delclos et al[21] as a complementary measure to the asthma score.[18] This algorithm is based on self-reports of both respiratory symptoms and allergic responses to animals and plants and was developed for a study examining asthma in Texas healthcare workers. The algorithm produces a dichotomous outcome and was validated against the provocative concentration of methacholine that resulted in a minimum of a 20% decrease in forced expiratory volume in 1 second (PC_{20}) from baseline, with a cut-point of $PC_{20} \leq 4$mg/mL.[21]

Hierarchical clustering of health outcomes associated with asthma was performed to help disentangle the complexity of asthma-related symptoms.[24] Five asthma health clusters were created as a result of this technique based on the similarity of symptoms between the participants: HC-1 no symptoms, HC-2 winter cough/phlegm, HC-3 mild asthma symptoms, HC-4 undiagnosed or untreated asthma, and HC-5 asthma attacks/exacerbations.

Another dependent variable was the frequency of recent wheeze, which is a sentinel symptom of asthma. It was defined as a "yes" answer to the question: "Have you had wheezing or whistling in your chest at any time in the last 12 months?"

2.5 Independent variables

The analyses focused on associations of health outcomes with workplace and home IEQ factors. The questions for work factors were related to the area(s) where the participant worked in the last 12 months and inquired about both moisture (ie, WD, mold growth [MG], mold odor [MO]) and renovations (ie, painting, floor renovations [FRs] such as replacing carpet, wall renovations [WR] such as replacing walls). The questions about home factors were related to the participant's house or apartment in the last 12 months and inquired about the same moisture factors as at work and about any renovations without addressing specific activities as done with the work setting.

Examination of the frequencies of workplace moisture factors revealed a large overlap of MG and MO with WD and with each other (Venn diagram in Figure S1). We created six work moisture categories: just WD without other moisture factors, WD and MG without MO (WD/MG), WD and MO without MG (WD/MO), WD and MG and MO (WD/MG/MO), MG and/or MO without WD (MG and/or MO without WD), and a work moisture reference group with no reports of relevant factors.

Significant overlap was observed in reports of painting, WR, and FR activities at work (Venn diagram in Figure S2). We created six work renovation categories: just painting (P) with no other renovations, painting and FR without WR (P/FR), painting and WR without FR (P/WR), painting and FR and WR (P/FR/WR), FR and/or WR without painting (FR and/or WR without P), and a reference group that comprised those who reported no renovation activities at work.

A Venn diagram in Figure S3 illustrates the overlap of reports of home moisture factors. Similar to workplace IEQ, there was considerable overlap of MG and MO with WD and with each other, and a large number of participants who reported only WD. This led to the creation of the same categories for home moisture factors as for workplace moisture factors, but their labels are preceded with “home”: home WD, home WD/MG, home WD/MO, home WD/MG/MO, home MG and/or MO without WD, and home moisture reference. The survey questionnaire asked about any renovations at home but did not differentiate between renovation types, so the only two categories were for any home renovation and the reference for no home renovation.

We examined the cross-tabulation of simplified workplace moisture and renovation groups (Table SI) and created five categories with a focus on investigating the interaction of MG and/or MO with WR and/or FR: painting or WD but no MG or MO and no WR or FR, MG and/or MO but no WR or FR, WR and/or FR but no MG or MO, MG and/or MO and WR and/or FR, and a reference category of no moisture and no renovation. We also examined the cross-tabulation of simplified work and home moisture groups (Table SII), and created five categories with a focus on investigating the interaction of work and home MG and/or MO: just work and/or home WD, MG and/or MO at work but not at home, MG and/or MO at home but not at work, both work and home MG and/or MO, and a reference category of neither work nor home moisture factors.

2.6 Statistical analysis

Regression models of health outcomes included covariates for all categories of work and home moisture and renovations, as well as the following risk factors and potential confounders: age (continuous, years), race (African American, White, other, unspecified), gender (female, male), smoking status (current, former, never), and allergic history (dichotomous). The allergic history variable was based on a self-report of at least one of the following: a history of nasal or sinus allergies (including hay fever), ever eczema or other skin allergies, ever animal allergies, ever dust or dust mite allergies, or latex or adhesive allergies. All regression models were weighted using the final weights for selection and nonparticipation.

BHR-related symptoms, current asthma, and wheezing or whistling in the last 12 months were modeled using binary logistic regression. These models produced an odds ratio (OR), 95% confidence interval (95% CI), and *P* value for each covariate. The association between the asthma health cluster (a multinomial outcome) and IEQ variables was investigated with a polytomous logistic model that yielded an OR and confidence interval. A negative binomial model was used to model asthma score, and the results were reported as a ratio of the mean score (RMS) with its corresponding 95% CI.[25]

Interaction effects were examined for work MG and/or MO and WR and/or FRs and for work and home MG and/or MO on both additive and multiplicative scales. We added the necessary covariates to regression models to test for the statistical significance of multiplicative interactions. Rothman recommended using the relative excess risk due to interaction and the synergy index (S) to investigate possible additive interactions.[26] We used the S index because it is preferred when evaluating effect estimates adjusted for potential confounders and calculated 95% CIs using the methods of Knol and Vanderweele.[27,28]

Data management, summaries, and all analyses were completed using SAS 9.4 statistical software (SAS Institute Inc, Cary, NC).

3 RESULTS

3.1 Frequency of demographic characteristics and asthma-related outcomes

The average age of the study cohort was 48.6 years, women outnumbered men 3-to-1, and the majority of participants were African American (62%). Most participants (83%) had never smoked, while only 5.6% were current smokers. Just over half (51%) of the study sample had a history of allergies. A fuller account of the distribution of participants by demographic characteristics is in Table 1.

One of the most common asthma-related outcomes (n = 522, 26%) was BHR-related symptoms (Table 1). Wheezing or whistling in the last 12 months (n = 291, 14%) was also fairly common, as was current asthma (n = 173, 8.5%). Asthma score ranged from 0 to 5, and one of every four participants (26%) had a score higher than 0. As the asthma score increased, indicating a more severe state, the frequencies decreased from 1511 (74%) with a score of 0 to 29 (1.4%) with a score of 5. Of the five asthma health clusters, the first three included hundreds of participants while there were only 63 (3.1%) and 85 (4.2%) participants in HC-4 undiagnosed or untreated asthma and HC-5 asthma attacks/ exacerbations, respectively.

3.2 Frequency of work locations and IEQ factors

Participants worked primarily in one of two facilities: hospitals (51%) and nursing homes (39%). The other 10% worked either in both hospitals and nursing homes or in other types of facilities. Within these facilities, the participants identified their primary work location. Where applicable, locations were combined into larger groups due to small counts. The most common work location was patient care, accounting for approximately half (n = 941, 46%) of the 2030 participants (Table SIII). Other locations with at least 3% of the participants were general medicine, outpatient care, or pediatric care (n = 237, 12%), medical and clinical laboratories (n = 171, 8.4%), surgery (n = 122, 6.0%), intensive care (n = 91, 4.5%), administration, education, psychiatric, or nonpatient care (n = 91, 4.5%), and emergency room (n = 71, 3.5%).

Almost three-quarters of the participants (n = 1497, 74%) reported at least one of the workplace moisture and renovation factors. Just over a third of participants reported factors related to moisture at work (n = 728, 36%). WD (n = 698, 34%) was by far the most frequent, followed by MG (n = 165, 8.1%) and MO (n = 147, 7.2%). A total of 227 (11%) reported MG and/or MO, and most of them also reported WD (197/227 = 87%). Reports of renovation at work were very common, with seven of ten people reporting at least one type of renovation (n = 1412). The most common type of renovation was painting (n = 1326, 65%), followed by WR activities (n = 862, 42%), and FR activities (n = 675, 33%). Most participants who reported FR or WRs also reported painting (886/972 = 91%).

The regression models used groupings of workplace moisture and renovation factors reported in the survey, as detailed in Section 1 (Table 1). Among the moisture at work categories, no moisture was the most common (n = 1302, 64%), followed by WD (n = 501, 25%), WD/MG/MO (n = 77, 3.8%), WD/MG (n = 71, 3.5%), WD/MO (n = 49, 2.4%), and MG and/or MO without WD (n = 30, 1.5%). The renovation groups in descending order of frequency were no work renovations (n = 618, 30%), P/FR/WR (n = 542, 27%), P (n = 440, 22%), P/WR (n = 265, 13%), WR and/or FR without P (n = 86, 4.2%), and P/FR (n = 79, 3.9%).

The overlap of the two sets of workplace IEQ factors is presented in Table SI. The two sets had 643 participants in common, which represented 88% of the 728 who reported a moisture factor and 46% of 1412 who reported a renovation factor. The five categories created to examine possible interaction effects of work moisture and renovation included 533 participants in the no moisture/no renovation reference category, 467 with paint and/or WD but no MG/MO or WR/FR, 58 with MG and/or MO but no WR or FR, 803 with WR and/or FR but no MG or MO, and 169 with the combination of MG and/or MO and WR and/or FR.

Participants reported about half as many instances of moisture or renovation at home (n = 785, 39%) as at work (n = 1497, 74%). Those with home IEQ factors included 538 (27%) with home moisture and 459 (23%) with home renovations and an overlap of 212. The relative frequency of home-based moisture categories resembled the trend for work: WD (n = 464, 23%) was the most common, followed by MG (n = 237, 12%) and MO (n = 119, 5.9%) (Figure S3). MG and MO had 94 participants in common, and 262 (13%) reported one or both of these factors. Of the categories created for regression models, no moisture was the most common (n = 1492, 73%), followed by home WD (n = 276, 14%), home WD/MG (n = 86, 4.2%), home WD/MG/MO (n = 83, 4.1%), home MG and/or MO without WD (n = 74, 3.6%), and home WD/MO (n = 19, 0.9%) (Table 1).

The overlap of work and home moisture factors is presented in Table SII. The two sets of factors had 241 participants in common, which represented 33% of the 728 who reported moisture at work and 45% of the 538 who reported moisture at home. The five categories created to examine possible interaction effects of work and home moisture included 1005 in the no moisture at work or home reference category, 581 with just WD at work and/or home, 182 with MG and/or MO only at work, 217 with MG and/or MO only at home, and 45 with MG and/or MO at both locations.

3.3 Association of asthma-related outcomes with indoor environmental factors at work and home

In almost all instances, the frequency of asthma-related outcomes was higher for those participants who reported moisture or renovation at work (Table 2). One of the MG and/or MO categories always had the highest frequency of asthma-related outcomes among the moisture and renovation categories. This was especially true for WD/MO (with 18% current asthma, 57% BHR-related symptoms, and 41% wheezing) and WD/MG/MO (with 1.29 mean asthma score, 7.8% HC-4 undiagnosed or untreated asthma, and 10% HC-5 asthma attacks/exacerbations). Among those who reported renovations at work, the category with all three factors—P/FR/WR—had the highest values for most asthma-related outcomes.

Participants who reported moisture or renovation at home often had a higher frequency of asthma-related outcomes than their respective no moisture or no renovation counterparts (Table 3). Like the pattern noted for these IEQ factors at work, the category of either home WD/MO or home WD/MG/MO had the highest frequency for most asthma-related outcomes among home moisture and renovation categories. These highest values were 16% current asthma, 26% wheezing, and 42% HC-3 mild asthma symptoms for home WD/MO, and 53% BHR-related symptoms, 0.96 mean asthma score, and 9.6% HC-4 undiagnosed or untreated asthma for home WD/MG/MO.

On the basis of the results from regression models, three of the five work moisture categories —WD, WD/MO, and WD/MG/MO—had positive associations with several asthma outcomes (Table 4). The effect estimates were somewhat less for WD than the other two categories. For example, RMS values for asthma score were 1.40 (95% CI: 1.13, 1.73) for WD, 2.27 (95% CI: 1.39, 3.71) for WD/MO, and 2.58 (95% CI: 1.72, 3.87) for WD/MG/MO. In contrast to these three categories, WD/MG was associated with only one health outcome, HC-2 winter cough/phlegm. Also, the addition of MG to the combination WD/MO did not yield substantially stronger associations with health outcomes. This was evident for the RMS values for asthma score as reported above, and also for BHR-related symptoms with OR = 3.60 (95% CI: 1.79, 7.23) for WD/MO and OR = 2.20 (95% CI: 1.24, 3.91) for WD/MG/MO, and for wheezing with OR = 3.24 (95% CI: 1.60, 6.57) and OR = 2.22 (95% CI: 1.22, 4.03), respectively. The final work moisture category MG and/or MO without WD included only 30 participants and had a statistically significant association with a single health outcome, HC-3 mild asthma symptoms.

Positive results for work renovation categories were most apparent for participants who reported all three factors P/FR/WR, with statistically significant elevated effect estimates for all health outcomes except HC-2 winter cough/phlegm (Table 4). This was the only work renovation category with positive results for current asthma (OR = 2.06, 95% CI: 1.24, 3.44), BHR-related symptoms (OR= 1.54, 95% CI: 1.11, 2.12), wheezing (OR = 1.99, 95% CI: 1.34, 2.97), HC-4 undiagnosed or untreated asthma (OR = 3.61, 95% CI: 1.47, 8.86), and HC-5 asthma attacks/exacerbations (OR = 2.90, 95% CI: 1.41, 5.94). At the other extreme, P had statistically significant results for just one outcome (asthma score), and P/FR was associated with none of the outcomes.

The results from regression models of health outcomes with covariates for moisture and renovations at home are in Table 5. Both home WD/MG and home WD/MG/MO had statistically significantly elevated effect estimates with three outcomes. These outcomes for home WD/MG were asthma score (RMS = 1.53, 95% CI: 1.03, 2.29), HC-3 mild asthma symptoms (OR = 2.51, 95% CI: 1.27, 4.97), and HC-5 asthma attack/exacerbations (OR = 3.73, 95% CI: 1.50, 9.23). Positive results for home WD/MG/MO were with BHR-related symptoms (OR = 3.06, 95% CI: 1.84, 5.09), asthma score (RMS = 1.70, 95% CI: 1.14, 2.53), and HC-4 undiagnosed or untreated asthma (OR= 3.17, 95% CI: 1.09, 9.19). The three home moisture categories WD, WD/MO, and MG and/or MO without WD, as well as home renovations, had statistically significant associations with none of the health outcomes. Home WD/MO included only 19 participants and the four effect estimates reported for this category had wide confidence intervals. Statistically significant elevated effect estimates were less common for moisture factors at home (6 of 33, or 18%) than at work (18/32 = 56%) (Tables 5 and 4, respectively).

3.4 Possible interactions of moisture and renovation factors

The evaluation of possible interaction of workplace MG and/or MO with WR and/or FR revealed statistically significant results on neither the multiplicative nor additive scale (Tables SIV and SV). Tables SVI and SVII present crude frequencies and effect estimates, respectively, for asthma outcomes by MG and/or MO only at work, only at home, and at both work and home. Among all those who reported MG and/or MO, most also reported WD: 87% (197/227) at work and 72% (188/262) at home. Each of the locational MG and/or MO categories had statistically significant positive associations with most of the health outcomes, and the effect estimates were usually considerably greater for both locations than for only at work or only at home. None of the tests for additive and multiplicative interactions was statistically significant. However, the S index for additive interaction with the outcome BHR-related symptoms was almost statistically significant (S = 2.57, 95% CI: 0.97, 6.80, $P = .058$), suggesting that the OR for MG and/or MO at both locations (OR = 5.54, 95% CI: 2.72, 11.24) was greater than the additive combination of effects for only at work (OR= 1.96, 95% CI: 1.29, 2.97) and only at home (OR= 1.81, 95% CI: 1.26, 2.61).

4 DISCUSSION

4.1 Summary of findings

Data from a sample of 2030 healthcare workers in New York City were analyzed to investigate the association of asthma-related outcomes with workplace and home IEQ factors. Moisture factors at work were common, reported by 728 (36%) of participants, and were risk factors for several asthma-related health outcomes. This was especially true for the categories WD, WD/MO, and WD/MG/MO (Table 4). Among these three, the effect estimates were usually somewhat greater for WD/MO and WD/MG/MO compared with WD. In addition, elevated effect estimates were much more common for WD/MO and WD/MG/MO than WD/MG. The finding that MO is a stronger risk factor for health outcomes than visible WD and MG has been reported previously.[14,29] IEQ researchers have noted that olfactory perception of mold is an important indicator of dampness and mold problems that are not visible, such as behind walls.[14] MO may indicate that mold is actively growing and metabolizing on currently wet materials.

Moisture factors were also common at home, reported by 538 (27%) of participants. MG and/or MO was almost equally frequent at home (n = 262) as at work (n = 227). WD, however, was less frequent at home (n = 464) than at work (n = 698). The regression models showed that home moisture factors had weaker associations with nearly all asthma-related outcomes compared with the corresponding workplace factors. This contrast might represent a difference in the severity of exposure, attributable in part to the fact that people have more control at home over the extent of MG and the length of time it is present. Additional research is needed to investigate differences in WD, MG, and related exposures in work and home settings. The investigation of MG and/or MO at both work and home yielded results that suggest a synergistic effect on the additive scale for BHR-related symptoms (Table SVII).

Renovations were much more common at work (n = 1412) than at home (n = 459), although the former was explored with more survey questions than the latter. Concerning renovations at work, positive associations with health outcomes were most common when all three factors P/FR/WR were present. This high-risk category potentially represents a greater variety, intensity, and length of exposure than the work renovation categories defined by just one or two factors. Renovations at home were associated with none of the health outcomes. In addition to the fact that renovations were three times more likely at work than home, the extent of renovations and the related exposures to dust and gases might have been more substantial at work as well.

4.2 Comparison to findings from similar studies

The findings from this study add to those from similar studies on WD, MG and MO, and renovations. For example, based on data primarily from residential settings, a 2011 review summarized results from meta-analyses that reported statistically significant associations of wheeze in adults and current asthma in people of all ages with indoor dampness or mold.[3] Prior studies of these IEQ factors specifically in workplace settings are not completely comparable to the current study due to differences in IEQ variables and health outcomes, but many agree in part with current findings.[15,16,30,31] For example, a 2018 review paper concluded that the onset and exacerbation of asthma were associated with mold exposure in work buildings, but the evidence was judged insufficient for a causal relationship and further prospective studies were recommended.[31] Regarding healthcare workplaces, a study of workers at a Veterans Administration Medical Center reported statistically significant elevated ORs for wheeze in relation to WD, condensation, wet carpet, MO, and removing/replacing interior materials, and for asthma with removing/replacing indoor materials.[15]

Other ORs were elevated but not statistically significant for wheeze (with MG, renovation or construction, and painting) and asthma (with WD, condensation, MG, MO, renovation or construction, and painting). Another hospital study found significant associations of work-related lower respiratory symptoms in the last year and post-hire onset asthma with an observational index of dampness and mold while controlling for self-reported residential dampness or mold.[16]

Researchers used data from the 2010-2012 follow-up of participants in the Respiratory Health in Northern Europe (RHINE) study to examine the onset of asthma-related outcomes relative to three different locational variables for dampness or mold during follow-up: only at work, only at home, and in both locations.[32] The effect estimates for both locations suggested an interaction on neither the additive nor multiplicative scale. When considering the interaction of IEQ factors at work and home, we focused on MG and/or MO, a subset of the more inclusive dampness and mold that the RHINE study examined. In contrast to that study's findings, we observed greater-than-additive interactions that were almost statistically significant for BHR-related symptoms. The interaction of mold at work and home needs to be investigated in other studies, especially prospective studies.

4.3 Strengths and limitations

One of the strengths of this study is the demographic composition of the sample. The participant base in this study had a different race distribution than that in other studies. Notably, our study featured substantial minority representation (for example, 62% African American) compared with other studies of healthcare workers in the United States, which had sample populations that were predominantly White.[10,15,33] African Americans represented 79% of nursing assistants, 72% of licensed practical nurses, and 51% of registered nurses in our sample, while national estimates are 36%, 30%, and 13%, respectively.[34] This high minority representation thus allowed us to study a population that is often overlooked. As many areas of the country feature diverse populations, the current results can be used as a basis for comparison with studies of healthcare workers in these regions. At the same time, this feature of the study sample might limit the generalizability of our results to other healthcare workforces.

This study also used IEQ factors to analyze a variety of asthma-related outcomes. Many of these outcomes have been used in the past with great success.[18] This study additionally utilized the newly developed asthma health clusters.[24] Demographic covariates were included in each model to adjust for potential confounding.

The study was cross-sectional by design. This prevented the examination of long-term temporal associations between workplace IEQ factors and the subsequent occurrence of asthma-related outcomes. We were unable to distinguish between OA and WEA, so results for the association of asthma-related outcomes with IEQ factors at work are evidence for WRA in general. The data on IEQ factors and health outcomes were both self-reported, potentially leading to bias in the results. In addition to inaccurate reports, participants with respiratory symptoms or diseases might have preferentially reported moisture and renovation factors that they considered to be health risks. Survey questions were limited to the last 12 months, and although the potential for bias still exists, the reported answers are likely more accurate than if this time period had been extended. One review article noted that effect estimates were higher when dampness and mold assessment was based on inspections by trained professionals rather than self-reports.[29] This observation suggests that positive effect estimates based on self-reported exposures are not necessarily biased away from the null.

This study had a very low participation rate of 13.3% of those invited and 22.5% of those contacted by telephone, which raises questions about whether the participants were representative of the sampling frame. Representation still remains a consideration in regard to the nonparticipants who completed the nonresponder survey or partially completed the main survey, as they may not have been representative of all nonparticipants. Despite our best efforts to control for these factors, it is impossible to know for certain whether the results are free from biases due to participation. Studies have shown that the participation rate is a weak indicator of the presence of bias.[35,36] Participation bias can be found across all levels of participation rates and may even be higher for studies with higher participation rates in some cases. Participants and nonparticipants gave enough information to develop weights to account for selection and nonparticipation biases, and these weights were used in every regression model.

4.4 Conclusions and additional research

Renovations and moisture factors were commonplace in healthcare facilities, potentially exposing building occupants to a higher risk of experiencing respiratory issues. We found that the risk of asthma-related outcomes was elevated for workers who reported WD, and somewhat higher if they also reported MO. Regarding workplace renovations, the risk for asthma-related outcomes was most evident among workers who reported the combination of painting, FRs, and WRs. The presence of MG and/or MO at both work and home might have a synergistic effect on the additive scale, as indicated by the results for BHR-related symptoms. Additional work is needed to confirm these results, both for the frequency of moisture and renovation factors in healthcare facilities, and the association of respiratory outcomes with these factors. More prospective studies are needed to strengthen the existing evidence. One way employers and employees in healthcare facilities can identify indoor dampness and mold is through a systematic observational survey. This can be accomplished using the NIOSH Dampness and Mold Assessment Tool for General Buildings, which is available online at https://www.cdc.gov/niosh/topics/indoorenv/mold.html.[37]

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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TABLE 1

Frequency of demographic characteristics, asthma-related outcomes, and IEQ factors for 2030 healthcare workers

	n[a] (mean, SD)	%
Demographic characteristics		
Age, in years (mean, SD)	(48.6, 11.4)	
Sex		
Female	1542	76
Male	487	24
Race		
African American	1249	62
White	266	13
Other	274	13
Unspecified	241	12
Smoking status		
Never	1676	83
Former	226	11
Current	113	5.6
History of allergies	1033	51
Asthma-related outcomes		
Current asthma	173	8.5
BHR-related symptoms	522	26
Asthma score (mean, SD)	(0.48, 1.02)	
Asthma score		
0	1511	74
1	277	14
2	115	5.7
3	63	3.1
4	35	1.7
5	29	1.4
Asthma health clusters		
HC-1: No symptoms	885	44
HC-2: Winter cough/phlegm	640	32
HC-3: Mild asthma symptoms	357	18
HC-4: Undiagnosed or untreated asthma	63	3.1
HC-5: Asthma attacks/exacerbations	85	4.2
Wheezing or whistling in last 12 months	291	14
IEQ Factors		
Work moisture categories		
No Moisture	1302	64
WD	501	25
WD/MG	71	3.5

	n[a] (mean, SD)	%
WD/MO	49	2.4
WD/MG/MO	77	3.8
MG and/or MO without WD	30	1.5
Work renovation categories		
No renovation	618	30
P	440	22
P/FR	79	3.9
P/WR	265	13
P/FR/WR	542	27
FR and/or WR without P	86	4.2
Home moisture categories		
No home moisture	1492	73
Home WD	276	14
Home WD/MG	86	4.2
Home WD/MO	19	0.9
Home WD/MG/MO	83	4.1
Home MG and/or MO without WD	74	3.6
Home renovations		
No home renovation	1571	77
Any home renovation	459	23

Note: Work and home moisture: WD, just water damage; WD/MG, water damage and mold growth; WD/MO, water damage and mold odor; WD/MG/MO, water damage and mold growth and mold odor; MG and/or MO without WD, mold growth and/or mold odor without water damage. The categories are the same for Home Moisture, except their abbreviated labels are preceded by "home." Work renovations: P, just painting; P/FR, painting and floor renovation; P/WR, painting and wall renovation; P/FR/WR, painting and floor renovation and wall renovation; FR and/or WR without P, floor renovation and/or wall renovation without painting.

Abbreviation: BHR, bronchial hyperresponsiveness; SD, standard deviation.

[a]Totals for any one characteristic may not add to 2030 due to missing data.

TABLE 2

Frequency of asthma-related outcomes by work moisture and renovation categories[a]

	Work moisture						Work renovations					
	No Moisture (n = 1302)	WD (n = 501)	WD/MG (n = 71)	WD/MO (n = 49)	WD/ MG/MO (n = 77)	MG and/or MO without WD (n = 30)	No Renovation (n = 618)	P (n = 440)	P/FR (n = 79)	P/WR (n = 265)	P/FR/W R (n = 542)	FR and/or WR without P (n = 86)
Asthma-related outcomes												
Current asthma	97	47	4	9	12	4	30	37	7	24	66	9
	7.5%	9.4%	5.6%	18%	16%	13%	4.9%	8.4%	8.9%	9.1%	12%	10%
BHR-related symptoms	274	147	23	28	36	14	118	95	22	83	183	21
	21%	29%	32%	57%	47%	47%	19%	22%	28%	31%	34%	24%
Asthma score (mean, SD)	(0.36, 0.88)	(0.61, 1.10)	(0.42, 0.95)	(1.18, 1.29)	(1.29, 1.65)	(0.73, 1.14)	(0.26, 0.74)	(0.43, 0.98)	(0.48, 1.11)	(0.51, 0.98)	(0.77, 1.27)	(0.49, 0.85)
Wheezing or whistling in last 12 months	148	80	11	20	23	9	58	54	8	40	121	10
	11%	16%	15%	41%	30%	30%	9.4%	12%	10%	15%	22%	12%
Asthma health clusters												
HC-1: No symptoms	657	181	21	2	19	5	333	205	31	98	181	37
	51%	36%	30%	4.1%	25%	17%	54%	47%	39%	37%	33%	43%
HC-2: Winter cough/ phlegm	379	172	34	21	23	11	183	141	30	87	176	23
	29%	34%	48%	43%	30%	37%	30%	32%	38%	33%	32%	27%
HC-3: Mild asthma symptoms	188	106	11	19	21	12	78	65	10	64	118	22
	14%	21%	15%	39%	27%	40%	13%	15%	13%	24%	22%	26%
HC-4: Undiagnosed or untreated asthma	29	23	2	3	6	0	9	13	4	6	29	2
	2.2%	4.6%	2.8%	6.1%	7.8%	0.0%	1.5%	3.0%	5.1%	2.3%	5.4%	2.3%
HC-5: Asthma attacks/ exacerbations	49	19	3	4	8	2	9	16	4	10	38	2
	3.8%	3.8%	4.2%	8.2%	10%	6.7%	1.5%	3.6%	5.1%	3.8%	7.0%	2.3%

Note: Work moisture: WD, just water damage; WD/MG, water damage and mold growth; WD/MO, water damage and mold odor; WD/MG/MO, water damage and mold growth and mold odor; MG and/or MO without WD, mold growth and/or mold odor without water damage. Work renovations: P, just painting; P/FR, painting and floor renovation; P/WR, painting and wall renovation; P/FR/WR, painting and floor renovation and wall renovation; FR and/or WR without P, floor renovation and/or wall renovation without painting.

Abbreviations: BHR, bronchial hyperresponsiveness; SD, standard deviation.

[a]The reported percentage is based on the column.

TABLE 3

Frequencies of asthma-related outcomes by home moisture and renovation categories[a]

	Home moisture						Home renovations	
	No home moisture (n = 1492)	Home WD (n = 276)	Home WD/MG (n = 86)	Home WD/MO (n = 19)	Home WD/MG/MO (n = 83)	Home MG and/or MO without WD (n = 74)	No home renovation (n = 1571)	Any home renovation (n = 459)
Asthma-related outcomes								
Current asthma	122	18	12	3	10	8	136	37
	8.2%	6.5%	14%	16%	12%	11%	8.7%	8.1%
BHR-related symptoms	336	80	30	7	44	25	382	140
	23%	29%	35%	37%	53%	34%	24%	31%
Asthma score (mean, SD)	(0.42, 0.95)	(0.54, 1.06)	(0.87, 1.24)	(0.95, 1.39)	(0.96, 1.45)	(0.47, 1.08)	(0.45, 1.00)	(0.60, 1.09)
Wheezing or whistling in last 12 months	190	44	21	5	20	11	209	82
	13%	16%	24%	26%	24%	15%	13%	18%
Asthma health clusters								
HC-1: No symptoms	707	101	21	5	22	29	730	155
	47%	37%	24%	26%	27%	39%	46%	34%
HC-2: Winter cough/phlegm	455	96	28	4	27	30	481	159
	31%	35%	33%	21%	33%	41%	31%	35%
HC-3: Mild asthma symptoms	235	60	25	8	19	10	256	101
	16%	22%	29%	42%	23%	14%	16%	22%
HC-4: Undiagnosed or untreated asthma	38	11	3	1	8	2	43	20
	2.6%	4.0%	3.5%	5.3%	9.6%	2.7%	2.7%	4.4%
HC-5: Asthma attacks/exacerbations	57	8	9	1	7	3	61	24
	3.8%	2.9%	10%	5.3%	8.4%	4.1%	3.9%	5.2%

Note: Home moisture: home WD, just water damage; home WD/MG, water damage and mold growth; home WD/MO, water damage and mold odor; home WD/MG/MO, water damage and mold growth and mold odor; home MG and/or MO without WD, mold growth and/or mold odor without water damage. Abbreviations: BHR, bronchial hyperresponsiveness; SD, standard deviation.

[a]The reported percentage is based on the column.

TABLE 4

Effect estimates for asthma-related outcomes by work moisture and renovation categories

	Work moisture[b]					Work renovations[c]				
	WD	**WD/MG**	**WD/MO**	**WD/ MG/MO**	**MG and/or MO without WD**	**P**	**P/FR**	**P/WR**	**P/FR/WR**	**FR and/or WR without P**
Asthma-related outcomes[a]										
Current asthma	1.11	NR[d]	1.76	1.28	NR[d]	1.54	1.19	1.47	**2.06**	1.94
	(0.73, 1.69)	n = 4	(0.78, 3.96)	(0.62, 2.61)	n = 4	(0.91, 2.61)	(0.49, 2.91)	(0.80, 2.69)	**(1.24, 3.44)**	(0.80, 4.69)
BHR-related symptoms	**1.34**	1.28	**3.60**	**2.20**	1.90	0.99	1.18	1.41	**1.54**	1.32
	(1.02, 1.77)	(0.70, 2.33)	**(1.79, 7.23)**	**(1.24, 3.91)**	(0.82, 4.38)	(0.70, 1.40)	(0.65, 2.16)	(0.96, 2.07)	**(1.11, 2.12)**	(0.72, 2.44)
Asthma score	**1.40**	0.90	**2.27**	**2.58**	1.29	**1.40**	1.42	**1.49**	**2.19**	**1.85**
	(1.13, 1.73)	(0.54, 1.50)	**(1.39, 3.71)**	**(1.72, 3.87)**	(0.66, 2.50)	**(1.06, 1.86)**	(0.87, 2.32)	**(1.08, 2.05)**	**(1.68, 2.86)**	**(1.16, 2.98)**
Wheezing or whistling in last 12 months	1.22	1.08	**3.24**	**2.22**	2.33	1.16	0.71	1.17	**1.99**	1.12
	(0.88, 1.71)	(0.52, 2.26)	**(1.60, 6.57)**	**(1.22, 4.03)**	(0.97, 5.60)	(0.76, 1.77)	(0.31, 1.62)	(0.72, 1.88)	**(1.34, 2.97)**	(0.49, 2.52)
Asthma health clusters										
HC-1: No symptoms (reference)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
HC-2: Winter cough/phlegm	**1.40**	**2.20**	**18.63**	1.96	3.05	1.06	1.26	1.16	1.24	0.93
	(1.06, 1.84)	**(1.15, 4.22)**	**(4.08, 85.05)**	(0.96, 4.01)	(0.96, 9.68)	(0.78, 1.45)	(0.70, 2.27)	(0.79, 1.70)	(0.90, 1.71)	(0.51, 1.71)
HC-3: Mild asthma symptoms	**1.66**	1.13	**27.25**	**2.82**	**5.92**	1.11	0.99	**1.82**	**1.78**	**2.24**
	(1.18, 2.35)	(0.48, 2.68)	**(5.74, 129.29)**	**(1.31, 6.06)**	**(1.88, 18.60)**	(0.73, 1.67)	(0.41, 2.38)	**(1.14, 2.92)**	**(1.19, 2.68)**	**(1.11, 4.48)**
HC-4: Undiagnosed or untreated asthma	**2.13**	NR[d]	NR[d]	**5.24**	NR[d]	1.75	NR[d]	1.11	**3.61**	NR[d]
	(1.08, 4.22)	n = 2	n = 3	**(1.66, 16.50)**	n = 0	(0.68, 4.49)	n = 4	(0.36, 3.47)	**(1.47, 8.86)**	n = 2
HC-5: Asthma attack/exacerbations	1.04	NR[d]	NR[d]	**2.98**	NR[d]	1.08	NR[d]	1.33	**2.90**	NR[d]
	(0.55, 1.95)	n = 3	n = 4	**(1.05, 8.49)**	n = 2	(0.50, 2.34)	n = 4	(0.52, 3.40)	**(1.41, 5.94)**	n = 2

Note: Work moisture: WD, just water damage; WD/MG, water damage and mold growth; WD/MO, water damage and mold odor; WD/MG/MO, water damage and mold growth and mold odor; MG and/or MO without WD, mold growth and/or mold odor without water damage. Work renovations: P, just painting; P/FR, painting and floor renovation; P/WR, painting and wall renovation; P/FR/WR, painting and floor renovation and wall renovation; FR and/or WR without P, floor renovation and/or wall renovation without painting. n, number of participants with the asthma-related outcomes. Highlighted results indicate $P \leq .05$.

Abbreviations: BHR, bronchial hyperresponsiveness; CI, confidence interval; IEQ, indoor environmental quality; OR, odds ratio.

[a]Results for current asthma, BHR-related symptoms, and wheezing are expressed as OR (95% CI) from logistic regression models. Results for asthma scores are expressed as ratio mean score (95% CI) from a negative binomial regression model. Results for asthma health clusters are expressed as OR (95% CI) from a polytomous logistic regression model.

[b] Work moisture: One regression model was fit for each asthma-related outcome. Each model included additional covariates for other IEQ factors at work (P, FR and/or WR with or without P) and at home (WD, MG and/or MO with or without WD, renovations), and other covariates to adjust for age, gender, race, smoking status, and history of allergies.

[c] Work renovations: One regression model was fit for each asthma-related outcome. Each model included additional covariates for other IEQ factors at work (WD, MG and/or MO with or without WD) and at home (WD, MG and/or MO with or without water damage, renovations), and other covariates to adjust for age, gender, race, smoking status, and history of allergies.

[d] Results not reported because the cell has less than five participants with the outcome.

TABLE 5

Effect estimates for asthma-related outcomes by home moisture and renovation categories[a]

	Home moisture					
	Home WD	Home WD/MG	Home WD/MO	Home WD/MG/MO	Home MG and/or MO without WD	Any home renovation
Asthma-related outcomes						
Current asthma	0.74	1.53	NR[b]	1.20	0.94	0.70
	(0.43, 1.30)	(0.77, 3.04)	n = 3	(0.56, 2.59)	(0.43, 2.09)	(0.46, 1.08)
BHR-related symptoms	1.16	1.34	1.12	**3.06**	1.36	0.97
	(0.83, 1.64)	(0.81, 2.24)	(0.35, 3.61)	**(1.84, 5.09)**	(0.80, 2.31)	(0.73, 1.28)
Asthma score	1.16	**1.53**	2.01	**1.70**	0.84	0.97
	(0.89, 1.51)	**(1.03, 2.29)**	(0.88, 4.60)	**(1.14, 2.53)**	(0.51, 1.38)	(0.78, 1.21)
Wheezing or whistling in last 12 months	1.00	1.64	1.40	1.31	1.08	1.07
	(0.67, 1.50)	(0.92, 2.94)	(0.39, 5.00)	(0.72, 2.36)	(0.51, 2.26)	(0.78, 1.49)
Asthma health clusters						
HC-1: No symptoms (reference)	1.0	1.0	1.0	1.0	1.0	1.0
HC-2: Winter cough/phlegm	1.20	1.65	NR[b]	1.14	1.20	1.28
	(0.85, 1.69)	(0.88, 3.10)	n = 4	(0.60, 2.15)	(0.66, 2.16)	(0.96, 1.70)
HC-3: Mild asthma symptoms	1.29	**2.51**	4.00	1.38	0.78	1.14
	(0.86, 1.94)	**(1.27, 4.97)**	(0.99, 16.20)	(0.69, 2.78)	(0.34, 1.78)	(0.81, 1.59)
HC-4: Undiagnosed or untreated asthma	1.10	NR[b]	NR[b]	**3.17**	NR[b]	1.30
	(0.50, 2.44)	n = 3	n = 1	**(1.09, 9.19)**	n = 2	(0.68, 2.49)
HC-5: Asthma attack/exacerbations	0.84	**3.73**	NR[b]	1.83	NR[b]	1.18
	(0.34, 2.06)	**(1.50, 9.23)**	n = 1	(0.68, 4.90)	n = 3	(0.66, 2.12)

Note: Home moisture: home WD, just water damage; home WD/MG, water damage and mold growth; home WD/MO, water damage and mold odor; home WD/MG/MO, water damage and mold growth and mold odor; home MG and/or MO without WD, mold growth and/or mold odor without water damage. n, number of participants with the asthma-related outcomes. Highlighted results indicate $P \leq .05$.

Abbreviations: BHR, bronchial hyperresponsiveness; CI, confidence interval; IEQ, indoor environmental quality; OR, odds ratio.

[a]One regression model was fit for each asthma-related outcome. Each model included additional covariates for moisture and renovation IEQ factors at work (WD, MG and/or MO with or without WD, P, FR and/or WR with or without P), and other covariates to adjust for age, gender, race, smoking status, and history of allergies. Results for current asthma, BHR-related symptoms, and wheezing are expressed as OR (95% CI) from logistic regression models. Results for asthma scores are expressed as ratio mean score (95% CI) from a negative binomial regression model. Results for asthma health clusters are expressed as OR (95% CI) from a polytomous logistic regression model.

[b]Results not reported because the cell has less than five participants with the outcome.