

Does Dampness and Mold in Schools affect Health? Results of a Meta-Analysis

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ABSTRACT

This paper provides meta-analyses of the published findings relating the respiratory health of occupants of schools with visible dampness, water damage, visible mold, and/or mold odor. Random effects models were used to develop central estimates and confidence limits for the associations of respiratory health effects with school dampness and mold. Eleven studies, all with cross-sectional designs, were included in the meta-analyses; however, analyses for some health outcomes were based on as few as four studies. Analyses were performed using data from adults and children combined, using only data from children, and using data from adults and children after excluding two studies. The central estimates of odds ratios from the meta-analyses were consistently above unity. The evidence of adverse health effects was strongest for cough and wheeze, which had confidence limits excluding unity in some or all analyses. The odds ratios of 1.32 for cough and 1.68 for wheeze suggest moderate increases in health risk. Studies not included in the meta-analyses provide additional evidence that dampness and mold in schools are associated with adverse health outcomes. These meta-analyses and the published literature not included in the meta-analyses suggest that dampness and mold in schools are associated with adverse respiratory health effects.

Keywords: dampness, health, meta-analyses, mold, respiratory, schools

Practical Implications: To reduce the risks of adverse respiratory health effects, school districts should design, operate and maintain school buildings in a manner that minimizes dampness and mold problems. When such problems occur, corrective measures should be undertaken promptly.

INTRODUCTION

Based on a large body of research, visible dampness, water damage, visible mold and mold odor in homes are associated with increases in respiratory and asthma symptoms including cough and wheeze, and are also associated with increases in development of the disease of asthma, although the specific agents that may be causing the increases in health effects are not known¹⁻⁵. The associations remain after controlling for a range of confounding factors. A smaller but significant body of research indicates that visible dampness and mold or mold odor in homes is associated with increases in respiratory infections⁶. Associations of visible home dampness and mold and mold odor with lung function are not as well established¹. Concentrations of microbial agents in the air or dust of homes are less consistently associated with adverse health effects than visible dampness or mold or mold odor¹.

We would anticipate that exposures to dampness and mold in schools are associated with the same health outcomes, although the risks from exposures at schools might be smaller because

students and teachers usually spend less time at school than at home. Less research has been published on the health consequences of dampness and mold in schools and no published review, focusing specifically on this topic, was identified.

This paper provides a meta-analysis of published findings relating the health of occupants of schools or day care centers (both adults and children) with visible dampness (which includes water damage), visible mold, and mold odor.

METHODS

Papers were identified using PubMed using the following search string (((Classroom OR School OR Daycare) AND (dampness OR mold) AND (Health or Asthma)). Supplemental searches were performed in Google Scholar with combinations of the same terms. The final PubMed search on September 4, 2018 identified 5195 papers. Titles of each paper were read. If the title indicated that a paper might be relevant, the abstract was read. If the abstract indicated that the paper was relevant, the full paper was read. For inclusion in the meta-analysis, we required that papers were published in peer-reviewed journals, described an original study (i.e., were not reviews of prior research), and provided odds ratios (ORs) and confidence intervals (CIs) for the associations of visible dampness and/or mold, and/or mold odor in schools (including classrooms, universities, or daycare centers) with one or more of the following health outcomes: breathlessness; cough; current asthma; dermal symptoms; nasal symptoms; throat symptoms; wheeze. We did not distinguish among dampness, mold, or mold odor as risk factors since visible mold is considered the result of excess dampness whether or not the dampness is reported, and excess dampness is typically accompanied by mold, even if the mold is not visible. Mold odor is also associated with mold, even when not visible. In addition, one study⁷ included water vapor condensation as one of several risk factors.

For inclusion, we required that studies controlled for potential confounders with multivariate statistical modeling or with study designs; however, we did not specify the specific confounders that must be controlled. Study subjects could be either school children or adults (e.g., teachers or other school staff). Data from studies at all grade levels were accepted. We excluded a study⁸ that used health data from the general population, and from office workers, as references. Studies of associations of dampness or mold in dorm rooms with health were excluded since we considered dorm rooms as residences. To limit the diversity of the studies used in the meta-analyses, the results of four intervention studies⁹⁻¹² were excluded. Also, to limit diversity, we excluded a study¹³ that assessed the level of improvement of health symptoms during weekends and vacation periods in subjects from moisture damaged schools compared to subjects from non-damaged schools.

Because of the very large number (5195) of papers identified via the search, it was not practical to compile the reasons for exclusion of each excluded paper. A very large majority of papers were excluded because they did not address the health consequences of dampness or mold in any type of building. Other main reasons for exclusion were as follows: 1) the study addressed health risks of dampness and mold in homes (potentially of school-age children) but not of dampness and mold in schools; 2) the study assessed associations of health outcomes with airborne molds or molds in dust, but did not include analyses with visible dampness or mold, or mold odor as the risk factor; 3) the study did not provide data for any of the specific health outcomes included in our meta-analysis.

The study setting and methods, key findings, and key strengths and weaknesses were summarized in tabular form. Study data were independently extracted by two authors and discrepancies resolved. Findings were also displayed in charts.

We applied random effects models to derive central estimates and confidence limits for the associations of health outcomes with mold, dampness, and/or mold odor. A separate model was run for each health outcome category. Random effect models were more appropriate than fixed effect models as we could not assume that the true effect size for all studies was identical since the studies varied according to subjects, investigators, and scenarios. In addition, because findings of multiple analyses within a single study may not be statistically independent, we applied a random effects model that adjusted for possible within-study correlations. The approach used was the same as in prior meta-analyses of dampness and mold with various respiratory outcomes^{6,2}. In each meta-analysis model, we included from each eligible study all relevant ORs for different but correlated risk factors (e.g., visible dampness, visible mold, mold odor). If a study included ORs for multiple specific health outcomes (e.g., cough and night-time cough) within a health outcome category (e.g., cough), the meta-analysis used the ORs for each specific health outcome.

We required that each analysis utilize data from four or more studies. Accordingly, calculations for throat symptoms and breathlessness, each with data from only three studies, were excluded. Additionally, from some analyses of subsets of studies, calculations for current asthma and dermal symptoms were excluded.

One study¹⁴ provide values of relative risk in place of ORs. We treated the relative risk values as equivalent to ORs. With prevalence rates of health outcomes far less than 100%, values of relative risk tend to be slightly smaller than ORs.

ORs and 95% CIs reported in primary studies were first log-transformed. The transformed results for each health outcome category were then combined using statistical software R¹⁵ metafor package¹⁶. A random effects model was fitted to the studies using the `rma` function that utilizes the inverse-variance method. These results were compared to those obtained from our main analysis using the `rma.mv` function following a multi-level random effects model procedure¹⁷ to account for both within-study and between-study variance, where a variance-covariance matrix of the sampling errors was estimated and constructed. The three levels of variance are: level 1 – sampling variance of the extracted effect sizes; level 2 – variance between effect sizes extracted from the same study; and level 3 – variance between studies. The three-level analysis approach is a practical way to account for interdependency of effect sizes without requiring primary studies to report the correlations between outcomes. Simulation studies showed that this method resulted in unbiased central estimates and corresponding standard errors^{18,19}. Further, the three-level approach allowed an examination of the differences in outcomes within studies (i.e. within-study heterogeneity) as well as an examination of differences between studies (e.g., between-study heterogeneity). We used the three level model as our primary analysis. The outputs of the models were exponentiated to produce the ORs and CIs for graphs and tables.

Ideally, all studies included in a meta analysis would be very similar in design and subject type with results that vary only because of sampling variance. Heterogeneity indicates that the variability in study results is not fully explained by sampling variance. Our analyses included calculations of p values from significance tests of heterogeneity. The I^2 statistic was also computed. The I^2 value describes the percentage of variability across studies due to heterogeneity rather than sampling error²⁰. Using the criteria outlined for Cochrane reviews, I^2 values below 40% may indicate that heterogeneity is unimportant, 30-60% may represent moderate heterogeneity, and greater than 75% indicates considerable heterogeneity²⁰. I^2 can be biased in small meta-analyses due to low statistical power.

The primary meta-analyses used data from all studies, regardless of the subject type (child or adult) or risk factor. A second set of analyses considered only studies with children as subjects. A third set of analyses omitted data from Bakke et al.²¹ and Taskinen et al.²². These two studies compared health effects of subjects of one or two schools with widely known dampness problems to health effects of subjects of one or two schools without such problems. We felt that the known history of dampness problems in these two studies could have biased the reporting of symptoms and that the small number of schools were additional weaknesses.

RESULTS

After applying inclusion criteria, eleven studies remained^{21,23,24,14,25-29,7,22}. The study features and results are compiled in Table S1 in the supplemental information. Nine studies provided data for cough, seven studies provided data for nasal symptoms, and six studies provided data for wheeze. Four studies provided data for current asthma and dermal symptoms. All included studies had a cross sectional design. In all studies, presence of dampness or mold was verified by trained inspectors, by members of the research team, or, in one case by teachers when the subjects were children. Thus, none of the studies relied on reports of subjects to indicate whether dampness or mold were present. The number of subjects in statistical tests ranged from 113 to 9271. In four studies, the subjects were adult teachers or staff, otherwise the subjects were school children. Many studies provided multiple sets of ORs and CIs, with each set applicable to a specific combination of health outcome and risk factor. Risk factors included in the meta-analyses were visible dampness, water damage, visible mold, mold odor, and combinations of these factors.

Most studies controlled for a broad set of potential confounders. Confounders commonly controlled in the studies within the meta-analyses included gender, age, socio-economic status, atopy, environmental tobacco smoke at home, and dampness and mold at home. One study²¹ controlled only for age and gender.

Table 1 provides the results of the three-level random effects modelling. We first consider the meta-analyses of all studies; i.e., studies with either adults or children as subjects and with the following risk factors individually or in combination: visible dampness; water damage; visible mold; mold odor. All of the resulting central estimates for ORs exceeded unity (1.0) with a range from 1.13 for dermal symptoms to 1.68 for wheeze. Ninety five percent CIs excluded unity for cough with OR = 1.32 (1.2 – 1.45) and for wheeze with OR = 1.68 (1.06 – 2.66). For nasal symptoms, the OR was 1.23 with a lower confidence limit of 0.96, indicating an increase in risk that was nearly significant since the lower CI was close to unity. P values for heterogeneity

ranged from 0.02 for wheeze and current asthma to 0.81 for cough. Figure 1 shows Forest plots with adjusted ORs and 95% CIs cough, nasal symptoms, wheeze, dermal, and current asthma.

Next consider the analyses of the subset of studies with children as subjects. Central estimates of ORs always exceeded unity with a range of 1.16 for nasal symptoms to 1.88 for wheeze. However, cough is the only outcome for which the 95% CI excluded unity with OR = 1.30 (1.17 – 1.45).

When we excluded data from Bakke et al 2008²¹ and Taskinen et al. 1999²², for the analyses with adults and children combined, most ORs changed minimally. For wheeze, the OR decreased from 1.68 to 1.43 and the lower confidence limit dropped to 0.97, just below unity.

When we applied the inverse-variance random effects model to adults and children for all studies, central estimates ranged from 1.16 for dermal symptoms to 1.66 for wheeze, with the CIs excluding the null in all cases except dermal symptoms. A table of these results can be found in Table S2 in the supplemental information. Relative to the three-level random effects models, this model yielded central estimates that tended to be slightly higher with CIs that were substantially narrower. The narrower CIs were expected since the standard models treat the multiple results from within studies as independent.

Table 1. Primary results of the three main, multi-level meta analyses .

Health Effect	Number of ORs	Number of Studies	OR (95% CI)	Heterogeneity p-Value ^a	Distribution of Variance I ² (%)	
					Within study ^b	Between-Study ^b
1. ADULTS AND CHILDREN AS SUBJECTS						
Cough	28	9	1.32 (1.20-1.45)	0.81	16	0
Current asthma	6	4	1.38 (0.72-2.63)	0.02 *	0	71
Dermal symptoms	15	4	1.13 (0.70-1.83)	0.38	0	42
Nasal symptoms	28	7	1.23 (0.96-1.59)	0.06	0	43 *
Wheeze	14	6	1.68 (1.06-2.66)	0.02 *	0	59
2. ONLY CHILDREN AS SUBJECTS						
Cough	18	6	1.30 (1.17-1.45)	0.44	23	0
Nasal symptoms	14	4	1.16 (0.86-1.56)	0.34	0	42 *
Wheeze	5	4	1.88 (0.66-5.37)	0.003 *	38	37
3. ADULTS AND CHILDREN AS SUBJECTS EXCLUDING DATA FROM [21] AND [22]						
Cough	26	7	1.30 (1.18-1.43)	0.90	13	0
Current asthma	6	4	1.38 (0.72-2.63)	0.02 *	0	71
Nasal symptoms	27	6	1.20 (0.92-1.58)	0.05 *	0	45 *
Wheeze	13	5	1.43 (0.97-2.09)	0.12	0	40

^a Test for heterogeneity between all ORs: * = p < 0.05.

^b One-sided log-likelihood-ratio test for significance of within-study variance and between-study variance: * = p < 0.05.

The p values from test of heterogeneity in all ORs and values of distribution of variance (I^2) are also listed in Table 1. Although there are several exceptions, for most analyses p values far exceeded 0.05, suggesting acceptable heterogeneity. For most of the cases, total variance can be attributed to the estimated sampling variance and the differences between ORs between studies. In comparison, differences between ORs within studies was a minor component of the total variance. The sum of I^2 values was less than 50% for most of the cases. I^2 was lowest for cough, for which data were available from nine studies. I^2 was greater than 50% for current asthma and wheeze.

For cough, which has confidence limits excluding unity in all analyses, p values for heterogeneity are 0.44 to 0.90 and a small fraction of variation is due to heterogeneity. For wheeze, which has a confidence interval excluding unity in the analyses of results from all studies, heterogeneity is high with $p = 0.02$ and an estimated 59% of variation due to heterogeneity. Excluding data from Bakke et al 2008²¹ and Taskinen et al. 1999²², reduces heterogeneity in the analysis for wheeze leading to a p value of 0.12. Heterogeneity is also significant for nasal symptoms ($p = 0.05$) for the final set of analyses excluding the two studies. Analysis of variance suggests that heterogeneity is due to between-study variance. Analyses of the subset of studies with children as subjects resulted in reduced heterogeneity for nasal symptoms ($p = 0.34$). This finding suggests that part of the between-study variance may be explained by whether the subjects were children or adults.

Funnel plots are provided in Figure 2, where odds ratios were plotted on logarithmic scale. Asymmetry in funnel plots can have multiple causes including heterogeneity, chance, and reporting or publication bias -- the less frequent publication of results with low ORs or with confidence intervals including unity³⁰. In the funnel plots, nearly all data points fall within the boundaries of the funnels which is suggestive of limited bias. None of the funnel plots have a particularly high level of asymmetry, considering the relatively small number of data points. In the plot for wheeze, there appears to be fewer than expected data points with high standard error and a small odds ratio, possibly indicating publication bias or other sources of bias.

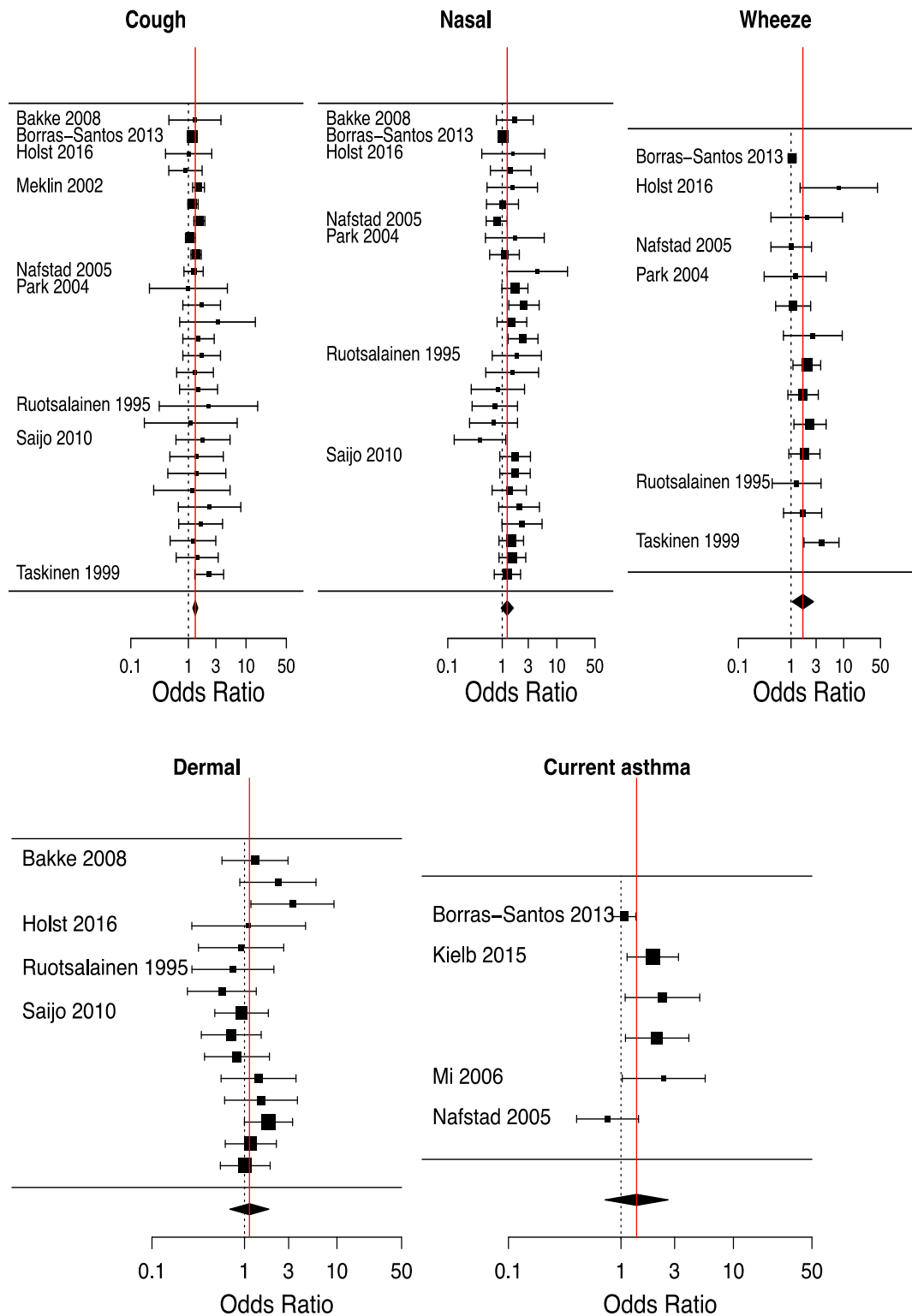


Figure 1. Forest plots for cough, nasal symptoms, wheeze, dermal, and current asthma with the area of each square proportional to the study's weight in the meta-analysis and the whiskers indicating the limits of the 95% CIs.

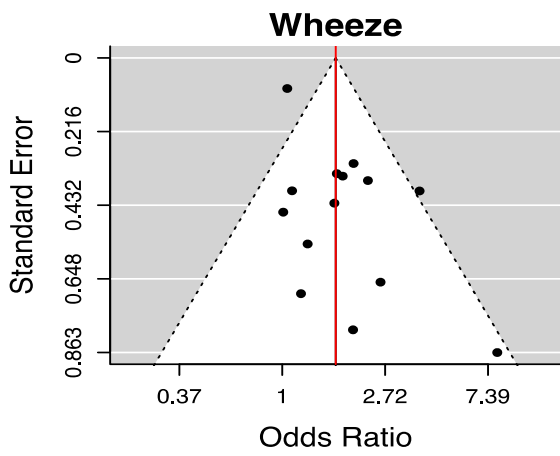
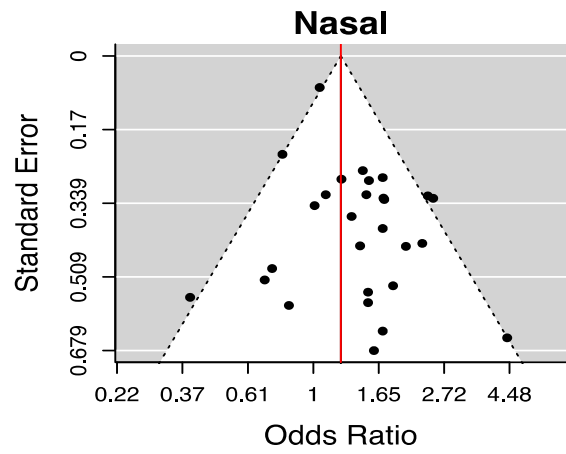
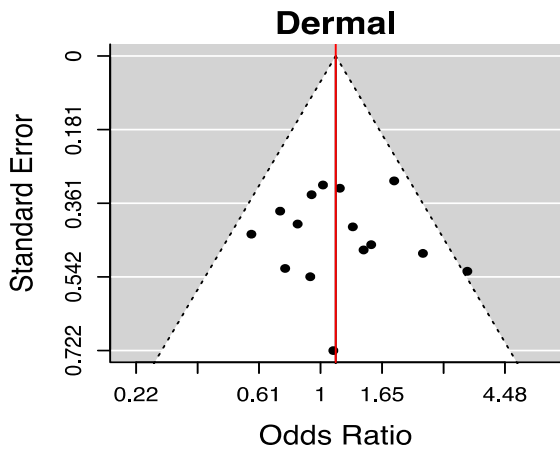
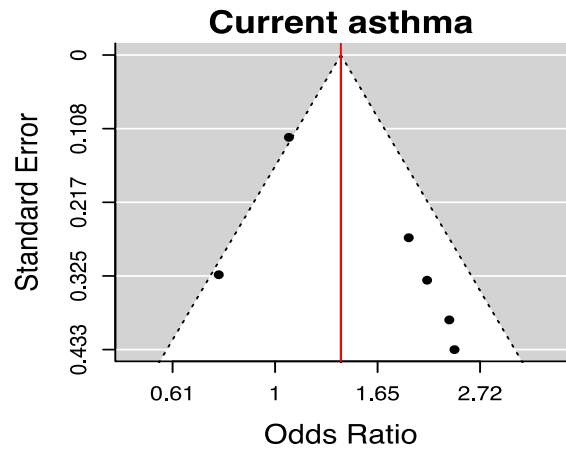
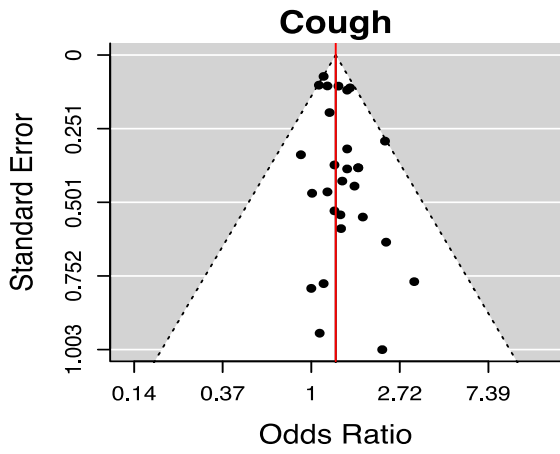


Figure 2. Funnel plots.

DISCUSSION

The central estimates of odds ratios from these meta-analyses are consistently above unity suggesting associations of adverse respiratory health effects with dampness and mold in schools. The suggestion of adverse health effects is strongest for cough and wheeze, which have confidence limits excluding unity in some or all analyses, and for nasal symptoms for which the lower confidence limit is just below unity. The ORs of 1.32 for cough and 1.68 for wheeze suggest moderate increases in health risk and the ORs near 1.2 for nasal symptoms suggest a small increase in health risk. Wide CIs for dermal symptoms and current asthma may be partly a consequence of the small number of studies providing data for these outcomes; however, other factors such as heterogeneity may also contribute to the wide CIs. Omitting data from the two studies having both few buildings and with well established, likely widely known, dampness problems led to minor changes in most ORs.

For cough, the heterogeneity in study results is small, while for wheeze and nasal symptoms there is considerable heterogeneity. Heterogeneity may be explained by the differences in the characteristics of the study participants and the diversity of the studies. For wheeze, heterogeneity is reduced when omitting data from two studies having both few buildings and buildings with well established, likely widely known, dampness problems. For nasal symptoms, heterogeneity is reduced when studies with children as subjects were analyzed separately. The tests for heterogeneity may have been underpowered because of the small number of studies providing data²⁰.

The ORs resulting from these analyses suggest the magnitudes of the fractional increases in respiratory health effects when schools have dampness or mold. For example, an OR of 1.5 suggests slightly less than a 50% increase in a health effect. The significance of these increases depend on the baseline proportions of subjects experiencing the respiratory health effects. Not all studies provided baseline prevalence rates of health effects in schools without dampness or mold. However, the study with the largest number of subjects reported the following prevalence rates among children in schools without dampness or mold: 2-4% for current asthma; 10% to 11% for wheeze; 13% to 20% for cough; and 24% to 31% for nasal symptoms.

The data underlying the meta-analyses are from studies that have, in general, controlled for a broad set of potential confounders. All but two studies have more than 250 subjects. The verifications, in every study, of dampness and mold by people (trained inspectors, research team members, or in one case teachers when the subjects were children) who were not study subjects is a strength.

There are many limitations to the meta-analyses reported here. The underlying data are entirely from cross sectional studies, a type of study subject to biases that cannot prove causal relationships. These studies can be subject to confounding and other limitations inherent in the study design, despite methods used to control for known confounders. For dermal symptoms and current asthma only four studies provided data. The health data are entirely self-reported and the occupants of damp and/or moldy schools may have been aware of the problems and their potential to cause health effects. The possibility of publication bias is always a concern for

research of this type. However, it is not the case that only statistically significant findings have been published. Most of the published data indicates non-statistically-significant increases in health risks. The funnel plots suggest limited publication bias and provision of funnel plots is a common practice for meta analyses, although the value of funnel plots is questionable when there are fewer than ten studies³⁰ which includes all of our analyses.

Ideally, school districts seeking to reduce dampness and mold in their buildings would have clear criteria defining the dampness and mold conditions that trigger remedial actions. However, the various studies cited have employed a variety of definitions for dampness and mold and there are no generally accepted criteria for distinguishing a problematic level of dampness and mold, which adversely affects health, from a non-problematic level of dampness and mold³¹. The lack of such criteria may hinder efforts to reduce dampness and mold-related health effects. Data from studies not included in the meta-analyses were also reviewed. Four studies described in five papers assessed whether renovations to correct dampness and mold problems in schools improved health^{9,12,10,11,32}. All four studies reported statistically significant improvements in some respiratory health outcomes after renovations. In one of these studies, a thorough renovation was associated with improved health but a partial renovation did not significantly improve health¹². Among identified studies measuring airborne levels of mold, with higher airborne mold levels five of seven reported statistically significant increases in respiratory symptoms or asthma or an improvement in nasal patency and worsening of inflammatory markers in nasal lavage fluids³³⁻³⁷. One of the seven studies reported a very small statistically significant decrease in wheeze with higher airborne mold³⁸ and another study²⁴ reported a decrease in atopic dermatitis with higher airborne mold. Eight studies reported in nine papers were identified that have investigated whether dampness and mold indicators were associated with objective (measured) health outcomes such as lung function or markers of allergic or inflammatory responses^{21,39,40,37,10,11,34,24,32}. Four of the eight studies reported statistically significant worsening of one or more objective health outcomes with indicators of building dampness or mold^{37,11,34,24,32}. However, with indicators of dampness and mold, one of these four studies also reported a statistically significant improvement in an objective health outcome²⁴. Four studies reported no statistically significant associations^{21,39,40,10}. Overall, the data from studies not included in the meta-analyses provide additional evidence that dampness and mold in schools increase health risks.

CONCLUSIONS

The results of these meta-analyses and the data from studies not included in the meta-analyses suggest increased risks of adverse respiratory health effects with presence of dampness and mold in schools. The suggested link with adverse health effects is strongest for cough and wheeze, which have confidence limits excluding unity in some or all meta-analyses.

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SUPPORTING INFORMATION

Supporting information is available at <https://onlinelibrary.wiley.com/doi/10.1111/ina.12588>

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