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Public Health and Economic Impact of Dampness and Mold

David Mudarri* and William J. Fisk+

*U.S. Environmental Protection Agency
Indoor Environments Division
Office of Radiation and Indoor Air, Office of Air and Radiation
1200 Pennsylvania NW
Washington D.C. 20460
Fax: 202 343 2394
Email: Mudarri.David@epamail.epa.gov

+Lawrence Berkeley National Laboratory
Indoor Environment Department
1 Cyclotron Road, 90R3058
Berkeley, CA 94720
Fax: 510 486 6658
Email: wjfisk@lbl.gov

Communications pertaining to this article should be with William Fisk

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ABSTRACT

The public health risk and economic impact of dampness and mold exposures was assessed using current asthma as a health endpoint. Individual risk of current asthma from exposure to dampness and mold in homes from Fisk et al. (2007), and asthma risks calculated from additional studies that reported the prevalence of dampness and mold in homes were used to estimate the proportion of U.S. current asthma cases that are attributable to dampness and mold exposure at 21% (95% confidence internal 12-29%). An examination of the literature covering dampness and mold in schools, offices, and institutional buildings, which is summarized in the appendix, suggests that risks from exposure in these buildings are similar to risks from exposures in homes. Of the 21.8 million people reported to have asthma in the U.S., approximately 4.6 (2.7-6.3) million cases are estimated to be attributable to dampness and mold exposure in the home. Estimates of the national cost of asthma from two prior studies were updated to 2004 and used to estimate the economic impact of dampness and mold exposures. By applying the attributable fraction to the updated national annual cost of asthma, the national annual cost of asthma that is attributable to dampness and mold exposure in the home is estimated to be $3.5 billion ($2.1 - 4.8 billion). Analysis indicates that exposure to dampness and mold in buildings poses significant public health and economic risks in the U.S. These findings are compatible with public policies and programs that help control moisture and mold in buildings.

PRACTICAL IMPLICATIONS

There is a need to control moisture in both new and existing construction because of the significant health consequences that can result from dampness and mold. This paper demonstrates that dampness and mold in buildings is a significant public health problem with substantial economic impact.

INTRODUCTION

There is a rapidly growing body of scientific literature examining the relationship between dampness and mold in buildings and associated health effects. Reviews by expert groups in

Europe (Bornehag et al. 2001; Bornehag et al. 2004) and the United States (IOM, 2004) draw similar conclusions:

- There is sufficient scientific evidence to conclude that there is an association between dampness and mold in buildings and an increased risk of adverse health effects for building occupants.
- The most common health effects appear to be associated with the respiratory system, although a much broader array of health outcomes has been reported.

In the United States, the growing scientific consensus on this issue has been accompanied by substantial public concern. This is evidenced by a rapid escalation in the number of mold claims against builders and their insurance companies, a growing tendency for insurance companies to drop mold coverage from their insurance policies, and the rapid growth in mold litigation and mold remediation expenditures (Levin, 2005; Prahl, 2002).

In light of new information that is accumulating on moisture and mold, and in recognition of growing public concern about these issues, this paper estimates the magnitude of public health risk and its associated economic impact. This will aid policy makers as they review current national measures to control moisture and mold in the built environment.

MAGNITUDE OF THE PUBLIC HEALTH RISK

To assess the magnitude of the public health risk from dampness and mold, we estimated the number of cases of current asthma attributable to dampness and mold exposure in U. S. homes. Current asthma is defined as doctor diagnosed asthma with symptoms or medication used in the past 12 months. While other health effects are also associated with dampness and mold, the lack of available data limits our assessments to asthma alone. The estimate is derived from data on increased individual risk associated with exposure to dampness and mold, and the prevalence of dampness and mold in U.S. homes. Evidence of health effects associated with exposures in offices and schools is presented in the appendix.

Increased risk associated with exposure to dampness and mold in housing

The scientific consensus of an increased health risk from dampness and mold[1] in buildings does not extend to quantification of that risk. However, in a companion paper in this journal (Fisk, et al., 2007) the authors estimate that exposure to dampness and mold raises the risk for various adverse respiratory outcomes by 30-50%. These estimates indicate a very substantial increase in risk for individuals exposed to dampness and mold in their homes. The estimates were derived from a meta analysis of 33 peer reviewed studies. Table 1 presents a summary of key results from the Fisk et al. (2007) meta analysis. The odds ratios in Table 1 are interpreted by the authors to reflect increases in relative risk of 30-50%.

[1] The term “dampness and mold” as used in this paper refers to conditions of dampness, or mold, or both.

Table 1. Summary health risks for dampness and mold in U.S. houses from Fisk, et al. (2007).

Outcome	# of Studies	Odds Ratio (95% CI)
Upper respiratory tract symptoms	13	1.70 (1.44-2.00)
Cough	18	1.67 (1.49-1.86)
Wheeze	22	1.50 (1.38-1.64)
Current asthma	10	1.56 (1.30-1.86)
Ever diagnosed asthma	8	1.37 (1.23-1.53)
Asthma development	4	1.34 (0.86-2.10)

The evidence of higher individual risk does not specifically address the primary causal agents responsible for the reported health outcomes. No one expects, for example, that dampness per se is a causal agent, but dampness (or moisture) is known to promote the growth and proliferation of dust mites, mold, and bacteria, exposure to which can result in allergic or infectious health outcomes. In addition, dampness promotes the degradation of some building materials and furnishings and can increase and/or alter their emissions. Whatever the primary causal agents, policies and programs that are successful in preventing and mitigating dampness and mold conditions would also be effective in reducing the public health risks and associated economic impacts.

Prevalence of dampness and mold exposure

The magnitude of the public health impact of dampness and mold also depends on the prevalence of dampness and mold. The American Housing Survey of the U.S. Census for 2003 reports that 10.4% of U.S. homes had water damage from exterior leakage, while 8% had water damage from interior leakage. However, the survey did not cover dampness or mold. There is otherwise no national database on the prevalence of dampness and mold in U.S. houses; however, Table 2 compiles data from studies that reported prevalence of various moisture related conditions in U.S. houses.

There is considerable variation in the prevalence estimates for each of the indicated moisture categories. For the “any dampness or mold category”, four of the studies report the prevalence to be 50% or more, while three report prevalence values below 50%. The largest study (Spengler, 1994) reports prevalence of dampness and mold in 50% of the homes. Excluding the Freeman study because it only included bathrooms, the population weighted average prevalence of dampness or mold from these studies is 47% in the U.S.

This suggests that approximately half or almost half of residents of housing units in the United States have a substantially higher risk of experiencing adverse respiratory related health effects because of their exposure to dampness and/or mold in their homes.

Estimate of current asthma cases attributable to dampness and mold exposure

The proportion of the U.S. population that reported having asthma varied non-uniformly between 7.1% and 7.8% from 2001 to 2005 (CDC, 2006a), with an average of 7.44% over that period. The resident population in the U.S. in 2004 was 293.7 million (U.S. Census, 2006). Assuming an overall prevalence rate of 7.4% would mean that approximately 21.8 million persons in the United States have asthma.

Table 2. Reported prevalence of dampness and mold in US houses

Author	**Location**	**Population (housing units)**	**Prevalence**			
			Mold or mildew	Water damage or dampness	Base-ment water	**Any dampness or mold**
Homes						
Brunekreef 1989	6 US cities	4625	30%	17%	32	**55%**
Chiaverini 2003	Rhode Island	2600		18%		**23%**
Freeman 2003	New Jersey	4291 (Hispanic)				**17% (in bathroom)**
Hu 1997	LA & San Diego	2041	8%			
Maier 1997	Seattle	925	54%	20%	22%	**68%**
Slezak 1998	Chicago	910 (Head Start)				**16%**
Spengler 1994	24 Cities in US & Canada	12,842	36%	24%	20%	**50%**
Stark 2003	Boston	492	38%	34%		**52%**
Population weighted average			33%	22%	23%	**47%***

* Excludes Freeman (2003) because it only considered bathrooms

The fraction of those current asthma cases attributable to dampness and mold exposure can be calculated using equation 1.

$$AF = [P(RR-1)]/[P(RR-1)+1] \qquad [1]$$

where AF is the attributable fraction, *P* is the prevalence of the risk factor (e.g. dampness and mold), and *RR* is the relative risk of exposure (e.g.. the ratio of the risk in the exposed population relative to the unexposed population.) The meta-analyses by Fisk et al., (2007) found that the odds ratio for current asthma in homes with dampness and mold was 1.56 (95% confidence interval: 1.3 to 1.86). The odds ratio is a close approximation of the relative risk when the prevalence of the health outcome is low (e.g. under 15%). Asthma prevalence is approximately 7% .Using the odds ratio of 1.56 as an approximation of the relative risk, and a 47% prevalence for dampness and mold, the central estimate for the fraction of current asthma cases attributable to dampness and mold exposure in housing is estimated to be 21% with an upper and lower confidence interval representing attributable fractions of 12% and 29% respectively.

Thus, out of the 21.8 million people reported to have asthma in the U.S., approximately 4.6 (2.7 to 6.3) million cases are estimated to be attributable to dampness and mold exposure in the home. This represents a substantial public health impact that could potentially be avoided with appropriate policies and programs designed to prevent or mitigate dampness and mold in the home.

MAGNITUDE OF THE ECONOMIC IMPACT

Table 3 provides an estimate of the total cost of asthma for both children and adults in the U.S. in 2004. This table is based on two prior estimates (Weiss et al. 2001 and Smith et al. 1997). Weiss et al., and Smith et al. estimated costs in 1998 and 1994 respectively. The costs from these studies were updated to 2004 by adjusting for population growth, inflation, and an increase in asthma prevalence. A medical cost inflator was used to update morbidity cost estimates, while a general inflator was used to update the mortality and indirect cost estimates using data from Table 706 of U.S. Census Bureau (2006). The adjustment for asthma prevalence was less straight forward because prevalence data were not available for 1994, the year for which Smith et al. (1997) provided estimates. A prevalence estimate for that year was therefore interpolated based on an annual average increment of prevalence between 1980 and 1996 (Mannino et al., 2002). In addition, the mortality estimate of Weiss et al. (2001) was adjusted downward to account for reduced mortality of asthmatics since 1998[2]. The estimates of morbidity (i.e., medical) costs from the two studies are similar; however medical costs are represented by actual medical expenditures, which in turn are influenced by access to medical care and may therefore underestimate the full national cost. The estimate of indirect cost based on Weiss et al. (2001) is much higher than the estimate based on Smith et al. (1997). Only Weiss included an estimate for mortality costs.

[2] The National Center for Health Statistics reports a decline in asthma mortality between 1998 (20.2 deaths per million) and 2002 (15 deaths per million) (Mannino et al., 2002,CDC 2006a), but estimates that 11% of that decrease is due to a change in coding scheme adopted in 1999(CDC 2006b). In the absence of mortality data after 2002, the mortality adjustment for 2004 was made using the 2002 data.

The selected cost estimate for this paper includes the adjusted Weiss et al. (2001) estimate for mortality, and an average of both adjusted estimates for the morbidity and indirect costs. Accordingly, for the purpose of this analysis, the total cost of asthma in the U.S. for 2004 is estimated to be approximately $17 billion dollars a year.

Table 3 also presents an estimate of the annual costs of asthma attributable to building dampness and mold. The attributable cost is calculated by multiplying the selected estimate of costs by the attributable fraction of 21% (CI interval of 12%-29%). The total annual asthma cost attributable to exposure to dampness and mold in homes is estimated to be approximately $3.5 billion.

Thus, there is an economic consequence from dampness and mold due to asthma alone that is in the range of billions of dollars per year. This should be significant enough to justify a significant community response. The cost of other health endpoints beside asthma along with the cost of building damage caused by dampness and mold add further justification.

Table 3. Total Annual Cost of Asthma and Annual Cost Attributable to Exposure

Source	**Cost in U.S. in $ billions ($ 2004)**				
	Mortality	**Morbidity***	**Indirect±**	**Total**	**Cost attributable to Dampness and Mold**
Weiss et al 2001	$1.9	$11.5	$4.0.		
Smith et al. 1997		$12.9	$1.5		
Selected estimate	**$1.9**	**$12.2**	**$2.7**	**$16.8**	**$ 3.5 ($2.1-$4.8)♦**

*Morbidity costs are the cost of medical care

± Indirect costs represent the value of lost work &/or school days

♦ Calculated from the central estimate of the attributable fraction bounded by the confidence interval

EVIDENCE OF RISK IN SCHOOLS, OFFICES, AND INSTITUTIONAL BUILDINGS

While the above population risk and economic impact estimates are limited to homes, evidence suggests that health risks in other buildings are also likely to be substantial. This conclusion is supported by research on the relationship between dampness and mold and health outcomes in schools, offices, and institutional buildings. While this research is not nearly as extensive as it is for housing, the evidence clearly points toward similar conclusions.

Table A1 and Table A2 in the Appendix compile the characteristics and key findings of research on the relationship between dampness or mold and occupant health in schools (Table A1) and offices and institutional buildings (Table A2). Papers published in refereed archival journals were identified from a computerized bibliographic search using the Pubmed bibliographic search system. The tables includes all relevant studies, whether or not the study found dampness or mold to increase the risk of health effects. However, only papers that included at least one respiratory or asthma related health outcome are listed in the tables, though most studies examined a variety of other health outcomes. Purely descriptive (non-analytic) case studies of mold problems in buildings were not reviewed.

14 studies of schools and 8 studies of offices and institutional buildings were reviewed. The studies measured a variety of risk factors and employed a variety of study designs. For schools (Table A1), the major risk factor for 5 studies was microbial concentrations in the air or in dust on floors, or visible/odorous signs of mold. (Ebbhoj et al. 2005; Meyer et al. 2003, 2005; Park et al. 2004; Rylander et al. 1998; Smedje et al 1997;). The major risk factor for the remaining 9 studies was dampness or mold in buildings at large. Most studies employed a stratified cross sectional design, which compared health outcomes among occupants of damp or moldy schools to health outcomes among occupants of reference dry schools. Most studies in schools controlled for a fairly broad range of potential confounding factors.

Risk factors in offices and institutional buildings (Table A2) included microbial concentrations in the air or in chair or floor dust (Chao et al. 2003; Park et al. 2006; Wan et al. 1999), dampness in the building at large (Cox-Ganser et al. 2005; or poor cooling coil drain pan drainage in the HVAC system(Mendell et al 2003). One study (Menzies et al. 2003) was an intervention study using ultraviolet germicidal irradiation of cooling coils in the HVAC that showed a reduction in risk from the intervention. The studies employed a variety of study designs. Several studies were cross sectional across multiple buildings (Chao et al. 2003; Wan et al. 1999, 1999b; Mendell et al. 2003), or multiple spaces within a building (Park et al. 2006). Two studies (Cox-Ganser et al. 2005, and Menzies et al. 1998) employed a case control design based on health symptoms. Finally, one study (Menzies et al. 2003) was a blinded crossover intervention study. As with the school studies, most studies for offices and institutional buildings controlled for numerous potential confounding factors.

The evidence supporting an association of dampness or mold in offices and institutional buildings with respiratory or other health effects of occupants is reasonably robust. Every study identified found one or more statistically significant association between dampness or mold and adverse respiratory or other health effects. In many cases, the magnitude of the increased risk of health effects in damp or moldy buildings was appreciable, e.g., greater than 100%. The health outcomes found to increase with dampness and mold, (e.g. lower respiratory symptoms typical of asthma, mucous membrane symptoms, headache, and fatigue) are the same as those found to be associated with dampness and mold in housing.

There are, of course, uncertainties in the results. Tables A1 and A2 only identify those findings that were statistically significant. Most studies failed to find associations between some risk factors and several of the adverse health effects assessed. However, given the crude measurement methods currently available in this field of research, and the multiple risk factors and health outcomes investigated, some failures to find an association would be expected even if there were true underlying causal relationships. On the other hand, since the studies performed numerous statistical tests, some of the positive associations found may be the result of chance. Finally, publication bias (i.e. less frequent publication of findings that do not conform to expectations) increases the likelihood that published studies would report positive findings.

Overall, there is good reason to believe that the results found in offices and institutional buildings reflect an underlying causal relationship between dampness and mold exposures and the reported health outcomes. There were a large number of significant associations between dampness and mold and adverse health; the increased health risk in some studies was quite large; there were no statistically significant inverse findings of *improved* health with dampness or mold; and the findings are consistent with the findings from the much larger body of research performed in homes[3].

Studies in schools also show significant health risks from dampness and mold, but the findings are not as robust as those in offices. In particular, most studies included a small number of buildings, so there is a substantial chance that building factors other than dampness and mold that differed among the damp and dry schools could have caused the reported differences in health outcomes. In addition, multivariate regression modeling is less likely to adequately control for confounding building factors with only a small number of buildings. A second major weakness is that many studies had a small number of subjects leading to poor statistical power for detecting increased health risks among occupants of damp and moldy schools.

Despite these weaknesses, the overall results indicate that adverse health outcomes are likely to be elevated among occupants of damp and moldy schools. Many of the studies found that damp or moldy schools, or molds and bacteria in floor dust were significant risk factors for a variety of health outcomes. Only one study reported an inverse finding of *improved* health with dampness or mold. While the extent to which the studies controlled for confounding varied greatly, studies that controlled for numerous potential confounders still found statistically significant health risks. Taken in isolation, the schools literature is non-conclusive. However, the consistency of findings from these school-based studies with the findings from homes, offices, and other buildings strengthens the case for adverse health effects in damp and moldy schools.

POLICY AND PROGRAM CONSIDERATIONS

Excess moisture in a building can result from a number of potential failures in the design, construction, maintenance and occupancy of buildings. There is a public interest in changing behaviors and practices in the building community that lead to these failures, and in mitigating problems when they do occur.

CONCLUSION

Effective moisture control in buildings supports public health. There is general consensus in the scientific community that exposure to dampness and mold substantially increases the risk of a variety of health effects, most notably those associated with the respiratory system. The increased risk to exposed individuals combined with the relatively high prevalence of dampness and mold in buildings means that large numbers of individuals are adversely impacted. In this paper, we estimated that approximately 4.6 million cases of asthma in the U.S. result from

[3] Dampness or microbial growth in air conditioning systems was not studied in homes, but was found to be a health risk factor in two of the office building. This is consistent with the broader association of air conditioning relative to natural ventilation as a health risk factor found in other studies and summarized by Seppanen and Fisk (2002).

exposure to dampness and mold and that the resulting economic cost of this health impact is approximately $3.5 billion annually. Public policies and programs can reduce these impacts by both preventing moisture and mold problems in buildings and mitigating them when they do occur.

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Table A1: Compilation of key features and results of research on dampness and health in schools, page 1.

Author Study Type	Buildings Subjects	Dampness or Mold related Risk Factors	Confounders Controlled	Key findings
Dangman et al. 2005 CS	55 teachers who had visited clinic in schools	Water damage or mold	None	Increase in respiratory Sx in teachers from water damaged schools (p = 0.075). (All 7 cases of incident asthma in teachers from water damaged schools.)
Ebbehoj et al. 2005 Stratified CS	522 teachers in 8 water damaged and 7 dry schools in Denmark	Water damage school, mold CFU in floor dust.	Personal and psychosocial factors	In women, headache and concentration problems were significantly increased with higher mold count in floor dust (For the highest versus lowest categories of mold counts, the risk of these symptoms increased more than fourfold.
Lander et al. 2001 CS	86 adults from 2 damp schools	Mold found in damp schools	Smoking, sex, years of employment, hay fever.	36% of subjects had positive histamine response to molds from the schools, i.e., were allergically sensitized to these molds.* Sensitization was associated with mucous membrane Sx [OR 4.7 CI 1.6 – 13.4].
Meklin et al. 2002 Stratified CS	4365 students in 24 damp schools & 8 dry schools in Finland	Damp/mold school vs. dry schl, airborne mold CFU	Age, sex. atopy. water damage	Some cough outcomes were significantly elevated in children from water damaged schools [OR of 1.4 to 1.5.]
Meyer et al. 2003 Meyer et al. 2005 Stratified CS	8 damp & 7 dry schools (Denmark) **2003:** 1053 students age 13-17 **2005:** 1024 students age 13-17	Mold & bacteria CFU in air, mold CFU & endotoxin in floor dust, actinomycetes	Age, gender, hay fever, smoking, asthma,T ,RH,CO_2, bldg age, type of ventilation, airway infection, endotoxin in floor dust	**2003 paper:** Higher extent of moisture and mold in school was assoc. with reduced eye Sx. High mold count in floor dust was significantly assoc with Sx for throat irritation, headache, dizziness [ORs of 2.3 to 2.9]. **2005 paper:** In boys, higher mold CFU in floor dust was signif. associated with Sx (eye, headache, concentration problems) with ORs of 3.5 to 8.2 for the highest vs. lowest mold CFU levels. In non-menstruating girls, higher mold CFU in floor dust was signif. assoc with headache and fatigue [p = 0.04 & 0.01].

* Only about 5% of the population test as allergic to molds using standard mold extracts. This study shows: a) a high portion of occupants can become allergic to the specific indoor molds they are exposed to, suggesting that the prevalence of allergy to molds may be much higher than often reported.

Key to table: assoc. = associated; CFU = colony forming units; CI = 95% confidence interval; conc. = concentration; CO = conc. of carbon monoxide in indoor air; CO2 = conc. of carbon dioxide in indoor air; CS = cross sectional; Dx. or dx. = diagnosis; NO2 = nitrogen dioxide conc.; OR = odds ratio; RH = relative humidity; RSP = airborne conc. of respirable particles; signif. = significantly (p<0.05); spirometry =one or more lung function outcomes measured via spirometry; Stratified CS = a study that intentionally selects damp and dry buildings; Sx. = symptoms determined via questionnaire; T = air temperature indoors; TVOC = total airborne volatile organic compound conc.; vent. = ventilation

Table A1: Compilation of key features and results of research on dampness and health in schools, page 2.

Author Study Type	Buildings Subjects	Dampness or Mold related Risk Factors	Confounders Controlled	Key findings
Park et al. 2004 Stratified CS	323 adult employees in 7 damp and 6 dry college buildings in U.S.	Water stains, Visible mold. Mold odor Indices of total dampness and mold	Age, sex. smoking., job status, year of hire, allergies, use of latex gloves	Water stain as contin. variable signif. assoc with increased wheeze [OR 2.3 CI 1.1-- 4.5] & visible mold [OR 2.0 CI 1.1-- 3.7]. Visible mold signif. assoc. with increased chest tightness [OR 2.6 CI 1.3 – 5.1.], & increased shortness of breath [OR 2.6 CI 1.3 – 5.1]. Increased nasal Sx. were signif. assoc. with water stains [OR 4.4 CI 1.2 – 15.3], with visible mold [OR 1.7 CI 1.0 – 3.0], with two indices of total dampness and mold [OR 2.4 CI 1.3 – 4.6] and [OR 2.5. CI 1.3 – 4.7]. Increased sinus Sx was signif. assoc. with water stains [OR 3.8 CI 1.1 – 13.4], visible mold [OR 2.0 CI 1.2 – 3.4], and an index of total dampness & mold OR 2.2 CI 1.2 – 4.1]. Increased throat irritation was signif. assoc. with water stains as a continuous variable [OR 2.4 CI 1.3 – 4.4] and mold odor [OR 2.3 CI 1.2 – 4.3].
Purokivi et al. 2001 After work vs after vacation comparison	37 adults from one damp school & 23 adults from 1 dry school in Finland	Damp school	Study uses within-subject comparisons	For workers from moist school, mucous membrane Sx and cough were increased after period of work relative to after vacation [$p < 0.05$]. Some inflammatory markers were signif. elevated after first period of work in damp school relative to after period of vacation [$p < 0.05$].
Rudblad et al. 2001 Stratified CS	39 teachers from 1 previously damp school & 30 teachers from 1 dry school in Sweden	Previously damp school	Age, Sex, Smoking, Allergy	Subjects from damp school had signif. more nasal swelling [$p < 0.01$] and nasal secretion [$p = 0.03$ for trend] in response to histamine challenge .
Ruotsalainen et al. 1995 CS	268 female daycare workers in 30 day care centers in Finland	Water damage, mold odor.	Age, sex, atopy. job type, smoking, psychosocial work index., ventilation type & rate, home dampness	No signif. assoc of Sx with water damage or mold odor except water damage plus mold odor was associated with eye Sx [OR 4.66 CI 1.48 – 14.6]. Other non-significant associations were indicated for water damage plus mold odor with nasal dryness [OR 1.84], nasal congestion [OR 1.52], mucosal Sx [OR 1.63], cough [OR 2.23], and Phlegm [OR 5.78]

Table A1: Compilation of key features and results of research on dampness and health in schools, page 3.

Author Study Type	Buildings Subjects	Dampness or Mold related Risk Factors	Confounders Controlled	Key findings
Rylander et al. 1998 Stratified CS	347 students age 6 – 13in 1 school with prior mold problem & 1 dry school	Prior mold problem, airborne conc. of inflammatory mold agent	Atopy	In non-atopics: Attendance of the damp school signif. assoc. with eye [$p = 0.006$], throat [$p = 0.03$], hoarseness [$p = 0.008$], wheeze ($p = 0.01$), tiredness ($p < 0.001$), headache ($p < 0.001$), and some cough outcomes ($P < 0.03$). In atopics: Attendance of damp school signif. associated with increased hoarseness [$p = 0.03$] and some cough outcomes [$p < 0.01$]
Savilahti et al. 2000 Savilahti et al. 2001 Stratified CS	2**000paper**: 397 students from 1 damp school and 192 from 1 dry school in Finland **2001 paper**: 69 students from damp school and 50 from dry school in Finland	Damp school	**2000 paper:** Pets in home, ETS, mold in home **2001 paper**: Sex, pets in home, ETS, # children & adults in home, type of housing.	**2000 paper:** Attendance at damp school signif. associated with more common colds , respiratory Sx, visits to doctors [$p < 0.05$] After renovations, only visits to doctor were signif. elevated in students from damp school. Only signif. improvement in health after renovation was in respiratory infection ($p < 0.05$). **2001 paper**: Attendance at damp school signif associated with increases in allergic sensitization [OR 2.68 CI 1.26 – 5.70], but not to common molds.
Smedje et al. 1997 CS	762 students age 13 – 14 from 28 classrooms in 11 schools in Sweden	Dampness, mold & bacteria CFU in air and floor dust	Atopy, daycare attendance; T, RH, CO2, NO2 TVOC, RSP; mite, cat, & dog allergen in dust; ETS at home, home dampness.	Current asthma signif. assoc. with higher bacteria and molds CFU in air[OR 1.5 CI 1.2 – 2.9 per 1000 CFU per m^3] and with higher RH [OR 1.8 CI 1.1 – 2.8 per 10% increase in RH]
Taskinen et al. 1997 Stratified CS	99 students from 3 damp schools and 34 from 1 dry school in Finland	Moldy versus dry school, mold & bacteria CFU in air	None	No signif. increase in any health outcome in students from water damaged school
Taskinen et al. 1999 Stratified CS	622 students age 7 – 13 from 1 damp and 1 dry school in Finland	Damp school; airborne mold & bacteria CFU	Age, gender, atopy	Attendance in damp school signif. associated with increase in wheeze [OR 3.8 CI 1.8 – 8.3], cough [OR 2.3 CI 1.3 – 4.1], allergic rhinitis [$p < 0.05$], and atopic eczema [$p < 0.05$], increase in emergency room visits[$p < 0.01$] and antiobiotic use [$p < 0.01$] in Spring (but not Fall)

Table A2: Compilation of key features and results of research on dampness and health in office and institutional buildings, page 1.

Author Study Type	Buildings Subjects	Dampness or Mold related Risk Factors	Confounders Controlled	Key findings
Chao et al. 2003 CS	98 adults in 21 offices in 4 bldgs	Mold CFU in air, floor and chair dust. Principal component analysis factors based on mold.	Personal and job factors. T, RH, CO_2, and dust load on floor and chairs	Higher chair mold CFU signif. assoc. with increased upper respiratory Sx [OR 1.87, CI 1.11 – 3.15); One principal component analysis factor from chair dust fungal counts associated with increased non-specific Sx group.
Cox-Ganser et al. 2005 **Main study** CS. **Supplemental stdy** compares outcome prevalence in study with reference populations	**Main study-** 888 adults from 1 damp building. **Supplemental study-** 248 adults in high resp Sx vs. low resp Sx, vs no resp Sx groups	Damp building	Smoking	**Main Study**: In study population of 888 adults relative to subjects of NHANES survey, signif. elevations in ever asthma [OR 2.2, CI 1.9 – 2.6], current asthma [OR 2.4, CI 2.0 – 3.0], adult onset asthma [OR 3.3, CI 2.7 – 4.0], wheeze [OR 2.5, CI 2.2 – 2.8], nasal Sx [OR 1.5, CI 1.4 – 1.6] eye Sx [OR 1.6, CI 1.4 – 1.7]. In study population relative to population in 100 representative office buildings, signif elevations in wheeze [OR 2.9, CI 2.2 – 3.7], cough [OR 2.7, CI 2.3 – 3.2], tight chest [OR 4.7, CI 3.8 – 5.7], shortness of breath [OR 4.6, CI 3.7 – 5.7] 7-fold more adult onset asthma after starting work in building compared to before. **Supplementary study**: Objective tests confirmed more abnormal lung function and breathing medication use in subjects with more self-reported Sx.
Park et al. 2006 CS	888 adults in one 20-story water damaged building	Fungi and endotoxin concentration in floor and chair dust ranked as low, medium, and high for each.	Age, gender, race, smoking, duration of occupancy.	In groups with highest vs. lowest fungal concentrations in floor dust, significant increases found for lower respiratory (OR 1.7, CI 1.02-2.77 to OR 2.4, CI 1.29-4.59); throat irritation (OR 1.7, CI 1.06-2.82); rash/itchy skin (OR 3.0, CI 1.47-6.19). Exposure-response relationships were generally linear. However, endotoxin increased associations of fungi on respiratory symptoms, i.e, presence of both was associated with greater increase than their added individual effects. Suggests how moisture might correlate with an effect size not directly associated with specific moisture-associated exposures.

Key to table: assoc. = associated; CFU = colony forming units; CI = 95% confidence interval; conc. = concentration; CO = conc. of carbon monoxide in indoor air; CO_2 = conc. of carbon dioxide in indoor air; CS = cross sectional; Dx. or dx. = diagnosis; NO_2 = nitrogen dioxide conc.; OR = odds ratio; RH = relative humidity; RSP = airborne conc. of respirable particles; signif. = significantly ($p<0.05$); spirometry =one or more lung function outcomes measured via spirometry; Stratified CS = a study that intentionally selects damp and dry buildings; Sx. = symptoms determined via questionnaire; T = air temperature indoors; TVOC = total airborne volatile organic compound conc.; vent. = ventilation

Soma Medical Sdn Bhd - No. 92A, Lorong Maarof Bangsar Park 59000 Kuala Lumpur - Malaysia - South East Asia
Tel: +60 3 2287 5790 - Fax: +60 3 2287 6790 - Email: sales@somamedical.net - www.somamedical.net - www.somamedicalnews.com

Table A2: Compilation of key features and results of research on dampness and health in office and institutional buildings, page 2.

Author Study Type	Buildings Subjects	Dampness or Mold related Risk Factors	Confounders Controlled	Key findings
Wan et al. 1999 CS	1113 adults in 9 air cond. office bldgs in Taiwan	Visible mold or mildew, signs of water damage, flooding.	Age, sex, atopy, job satisfaction, perceived ventilation.	Skin Sx increased signif. in buildings with mold (OR 2.97, CI 1.52 – 5.82,) with water damage (OR 3.36, CI 1.70 – 6.63), and with flooding (OR 2.6, CI 1.19 – 2.56). Headache increased signif. with mold (OR 1.61, CI 1.01 – 2.56) Non-signif. increases in many other Sx including shortness of breath with mold, water damage, or flooding.
Wan et al 1999b CS	109 adults in 8 office and 8 daycare bldgs in Taiwan	Visible mold, water damage, flooding. Mold bacteria CFU, & endotoxin in air. β-1,3-glucan in air .	Sex. Ventilation rate. Type of building	Shortness of breath was significantly increased in buildings with mold (OR 20.75, CI 2.23 – 193.5)
Mendell et al. 2003 CS	2345 adults in 80 complaint office bldgs in U.S.	Water in outdoor air intake, moist internal duct insulation, poor drain pan drainage, water damage in workspace.	Age Sex. Smoking status. Asthma status	Poor cooling coil drain pan drainage associated with at least 3 of the following Sx: Wheeze, shortness of breath, tight chest, cough (OR 2.6, CI 1.3 – 5.2) Having all three of wheeze, shortness of breath, cough (OR 2.8, CI 1.1 – 5.2)
Menzies et al 1998 CS based on Sx	214 adults in 6 office bldgs in Canada	Mold CFU in air, floor dust & HVAC supply air. Indoor minus outdoor humidity	Age, sex, atopic status, smoking; T, RH, CO2, CO, TVOC, tot. suspended particulates	For workers with Sx versus those without Sx, the probability of detectable *Alternaria* in office air was signif. elevated (OR 4.2, CI 1.1 – 16.2); For workers with Sx, there was a significantly higher indoor air minus outdoor air moisture level ($p < 0.010$)
Menzies et al 2003 Blinded crossover intervention study	771 adults in 3 office bldgs in Canada	Ultraviolet germicidal irradiation of cooling coils as an intervention	Within-person analysis controls personal factors T, RH, CO2, NO2, & Ozone.	Operation of ultraviolet germicidal system associated with significant reduction in Sx as follows: Any Sx (OR 0.8, CI 0.7 - 0.99) Mucosal Sx (OR 0.7, CI 0.6 - 0.9) Respiratory Sx (OR 0.6, CI 0.4 - 0.9) Musculoskeletal Sx (OR 0.8, CI 0.6 -1.1) [increased susc in atopics]

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Soma Medical Sdn Bhd - No. 92A, Lorong Maarof Bangsar Park 59000 Kuala Lumpur - Malaysia - South East Asia
Tel: +60 3 2287 5790 - Fax: +60 3 2287 6790 - Email: sales@somamedical.net - www.somamedical.net - www.somamedicalnews.com

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