Topic A6: Health and indoor air epidemiology

INDOOR DAMPNESS AND MOLD AS INDICATORS OF RESPIRATORY HEALTH RISKS, PART 3: A SYNTHESIS OF PUBLISHED DATA ON INDOOR MEASURED MOISTURE AND HEALTH

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SUMMARY

In developing evidence-based, health-protective guidelines for indoor dampness/mold, one goal is to quantify the health risks from indoor dampness. A first step is to synthesize existing epidemiologic findings on measured home moisture and health. Findings were combined from the only two published studies assessing associations between measured wall moisture and health. Both studies used the same make of two-pin, electronic resistance-type moisture meter on gypsum plaster-on-brick walls in UK homes. Both showed dose-related increases in asthma exacerbation with higher measured moisture, in one study beginning at 10-15% wood moisture equivalent (%WME) and reaching an odds ratio of 7.0. Further research is needed to extend this relationship to include measured "water activity" (A_w, a scale assessing moisture availability directly relevant to microbial growth), other types of moisture meters, and other building materials. Such assessments will be useful until acceptable levels of identified dampness-related causal agents are determined. Meanwhile, evidence-based, health protective, quantitative guidelines for building-related dampness would have great utility.

INTRODUCTION

The Indoor Air Quality Section (IAQS) of the California Department of Public Health (CDPH) is developing strategies for producing evidence-based, health-protective, quantitative guidelines for indoor dampness/mold. Ideally, such guidelines for building dampness would be based on quantitative, dose–response relationships between measured, identified, dampness-related causal agents (presumably microbial but possibly also chemical) and specific health outcomes. However, although consistent associations have been demonstrated between subjectively identified dampness or mold and many health effects, we have very limited evidence on dose–response, and also no consistently demonstrated relationships between *measured* microbial factors and specific health effects (Mendell et al., 2011). The best current advice is to use subjective, qualitative observations of dampness or mold to guide remedial actions, considering that more area of evident dampness or mold seems to increase the health risks; however, specific acceptable levels of these factors cannot yet be specified.

Research is ongoing both to better quantify relationships of health with subjectively assessed dampness and mold, and to identify specific dampness-related causal agents and quantify their relationships with health effects. Meanwhile, an additional avenue of research has received little attention: promising initial findings on the relationship between *quantified building moisture* and health are available but have not been synthesized and interpreted for use. This paper describes work aimed at developing evidence to support health-protective guidelines for measured building moisture. This was motivated by a prior study reporting associations between measured residential moisture and respiratory health (Williamson et al., 1997).

METHODS

We searched PubMed to identify relevant articles. Published findings of identified studies were abstracted to identify common findings, regarding both exposures and health outcomes. For each identified study, we communicated with an author to clarify the interpretation of moisture measurements, and the materials in measured walls. We combined the findings of the available studies on associations between measured material moisture and health effects.

RESULTS AND DISCUSSION

One additional publication was identified. The two identified studies (Williamson et al., 1997; Venn et al., 2003) used the same make but different models of a two-pin, electronic resistance-type moisture meter (Protimeter Surveymaster^{TM} (PS), General Electric Company, Billerica, MA, U.S.), and had some differences in wall measurement protocols, ways of interpreting moisture readings, patient populations, and assessment of health outcomes. Both estimated increased health risks associated with moisture using odds ratios (ORs), a measure of the strength of association between an exposure and a health effect. Both moisture meters measured the moisture content (MC) of non-wood materials as % wood moisture equivalent (%WME), the theoretical %MC of wood in equilibrium with the material.

Williamson et al. (1997), studied patients with doctor-diagnosed asthma, aged 5–44 years, in Scotland. Researchers measured dampness in homes just above skirting board (baseboard) height, at three points on each wall in every room of a dwelling. Dampness was graded semi-quantitatively into five categories based on percentage of the meter's full-scale deflection: 0 (<10%), 1 (11%–25%), 2 (26%–50%), 3 (51%–75%), and 4 (>76%). Dampness was quantified as the sum of all grades (total dampness score) and as the maximum measurement for each home. The researchers reported multiple positive adjusted associations: strong, dose-related associations between measured dampness and asthma severity among asthmatics (r = 0.3, p = 0.006), with an adjusted linear regression coefficient (95% confidence interval (CI)) of 2.10 (0.53-4.07) per unit of dampness score (range 0–85). They also reported adjusted ORs (95% CIs) for asthma case (vs. control) status and any dampness of 3.0 (1.6–5.6), which exceeded the ORs for subjective inspector-determined visible mold. There were also, in adjusted analyses, significant negative correlations between total dampness score and both % predicted forced expiratory volume in one second (FEV_1) and FEV_1/full vital capacity (FVC).

Venn et al. (2003), in a case–control study in children aged six to eight years, measured residential exposure in Nottingham, England to volatile organic compounds, dampness, environmental tobacco smoke, and nitrogen dioxide, to estimate the independent effects of these pollutants on the risk and severity of persistent wheezing illness (Venn et al., 2003). The investigators used a later digital version of the analog meter used by Williamson et al. (1997). Venn et al. took single measurements per room in the living room, bedroom, and kitchen. Their measurements also were primarily from perimeter walls (facing the outdoors or exterior), and were made at a higher position (~30 cm above skirting boards). Venn et al. classified meter readings into four categories directly from meter %WME readings: 1 (very low, 0–10), 2 (low, 10.1–15), 3 (medium, 15.1–20), and 4 (high, >20). Measured dampness had significant associations with multiple health outcomes, including case status (persistent wheezing assessed at times three years apart, which we will consider equivalent to current asthma) and increased symptoms in cases (which we will consider equivalent to asthma exacerbation). For example, measured bedroom dampness had a positive dose-related association with frequent night-time exacerbations in cases; the OR (95% CI) for a single slope estimate was 2.51 (1.36–4.64) for each increase in dampness category across all four categories. In category-specific analyses, even the low category, compared to the very low category, had a significantly elevated OR of 2.3 for bedroom dampness and frequent night-time exacerbations. The combined medium and high categories, compared to very low, had a significantly elevated OR of 7.0. Moderate or high levels of living room and kitchen dampness also had significantly elevated ORs for frequent night-time symptoms (3.9 and 3.6, respectively). Associated increases in frequent day-time symptoms were smaller. Living room dampness had a positive dose-related association with persistent wheeze case status, with an OR (95% CI) for each increase in dampness category of 1.32 (1.00–1.75).

We obtained additional information on both studies about analyses of PS moisture meter readings (personal communication: George McGill, McGill Consultancy, Glasgow; Andrea Venn, City Hospital, Nottingham), and about the materials in the measured walls (personal communication: George McGill; Derrick Crump, Cranfield University, Cranfield). We also confirmed that readings on the two models of meter used in these studies were equivalent, based on identical calibrations (personal communication: Chris Ranwell, General Electric).

Meter readings in Williamson et al. (1997) were confirmed to be categorized based on the percentage of the meter's full-scale deflection, with actual scale values ranging from 14–26. We converted these categories (0–4) to the equivalent scale readings (Figures 1 and 2) using an image of the scale from the manufacturer. For instance, category 3, >51%–75% of the scale reading, was converted to >20–23. Moisture analyses in Venn et al. (2003) were confirmed to have used the digital readout, ranging from 0–99, on their model of PS meter. The scales on both meters, per the manufacturer, had been calibrated to provide "%WME," the gravimetric moisture content of wood in equilibrium with any measured material. In both studies, moisture readings within houses were analysed for associations with health outcomes.

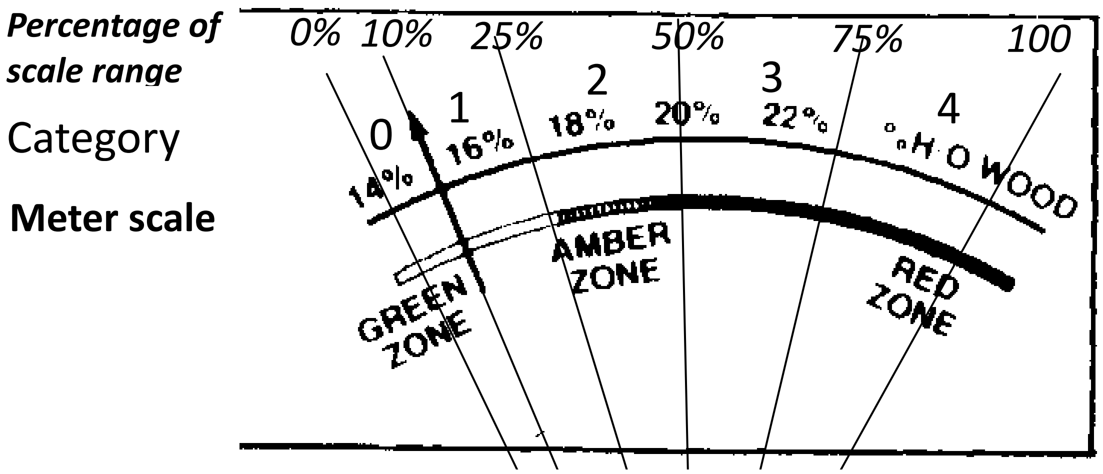

Figure 1. Meter display on the Protimeter Surveymaster™, showing the scale and categories as reported in Williamson et al. (1997). The scale image is from Protimeter™ Technical Data

Sheet no. 52, 1984, rev 1996, “How to Measure Moisture in Buildings” Wood-moisture-equivalent or per cent moisture content?”

Figure 2. Combined findings from two UK studies, both using Protimeter Surveymaster™ moisture meters, on moisture meter readings and severity or exacerbation of asthma

We considered together specific findings of the two studies on measured home wall moisture and respiratory outcomes in asthmatic subjects: Williamson et al. on severity of asthma in children and adults, and Venn et al. on frequent night-time exacerbations in asthmatic children. The studies agreed in finding increased risk of asthma exacerbation or severity associated with higher levels of measured wall moisture, and both studies found dose-related increases. Venn et al., however, found risks at lower moisture levels, and compared to the much lower baseline levels used in that study, much higher increased risks at the highest moisture levels than did Williamson et al. The Williamson et al. findings considered the baseline risk level meter reading to be up to 17, and assessed increasing risk above 17, or above 20, using only dichotomized comparisons. The Venn study, in contrast, considered the baseline risk level to be only up to 10, and assessed increasing risk for multiple categories above 10: >10–15, >15–20, and >20. The “low” and even part of the medium categories in Venn et al., both associated with increased health risks, were within the “none” category in Williamson et al.; the entire low and medium categories in Venn et al. were within the non-severe category in Williamson et al. Thus, even though the Venn et al. study demonstrated increased risk above readings of 10, compared to the Williamson et al. demonstration of increased risk associated with moisture readings above 17, the two studies did not disagree about the lower levels of moisture that might indicate increased risk: the Venn et al. study simply assessed risks at lower moisture levels than the Williamson et al. study. Although 10–15 %WME may be considered dry by some, it corresponds to an A_w of 0.6–0.8, including levels sufficient for growth of many fungal species and some bacteria (Chen et al., 2014).

The two studies reviewed here each suggest dose-related increases in respiratory morbidity among persons with asthma in association with increasing measured moisture in home walls. No other published studies have assessed these relationships, although others have reported dose-related increases of various respiratory health effects with more subjective assessments of dampness and mold (Platt et al., 1989; Park et al., 2004). This suggests that measured moisture may be useful in quantifying increased dampness-related health risks. However, because moisture in buildings may vary substantially by location and over time, and may occur in locations in building envelopes or ventilation systems inaccessible to moisture measurements, even the fullest development of this method is unlikely to allow complete identification of all building dampness that requires remediation. Furthermore, %WME is not a metric of material moisture directly relevant for microbial growth and varies across materials in ways unrelated to the water requirements of microorganisms. Another metric, A_w, is related directly to water available for meeting the moisture requirements of specific microorganisms in a way that does not vary across materials (Ezratty et al., 2007). While historically A_w could not be measured in the field, a new device may allow this (Aqualab, 2013). Still, if even a subset of problematic building-related moisture could be quantified with %WME and systematically related to health risks, it would be an advance over currently available assessment strategies. Combining quantified moisture with qualitative indices (e.g., Park et al. (2004)) may provide advantages over either approach alone.

The ultimate goals of research on measured indoor moisture and health could be:

- To confirm whether measured surface moisture in homes is a useful objective predictor of dampness-related respiratory health effects.
- To help focus future research studies so as to further refine moisture measurement strategies to optimally predict dampness-related health risks.
- To inform public health strategies using objective moisture meter measurements to prevent dampness-related health risks in homes.

Limitations

While the findings in these two studies are consistent, even to the extent of the building materials measured and the make of moisture meter used, the Venn et al. paper provides the most detailed data, using a wider range and more categories of measured moisture. What current application do findings from these two studies offer as guides to acceptable and unacceptable levels of measured moisture in buildings in general, including those in the U.S.?

A number of issues limit the direct application of these findings of dose-related increases in risk of asthma exacerbation with levels of measured home moisture of 10–15 %WME or higher, using a PS in pin mode on the interior side of exterior walls of gypsum plaster on brick. Uncertainties include:

- How do “relative” readings on the PS compare to readings from other samples of PS meters, meters from other manufacturers, or any meters in pinless mode, or to readings taken at different temperatures?
- How would health risks that correlated with measured moisture of gypsum plaster on brick, in UK homes, correlate with the same measured moisture, even using the same moisture meters, in typical gypsum board walls in the U.S. or other types of

construction, given that (1) gypsum board on hollow walls is covered with microbe-supporting cardboard, and (2) moisture on the inside of exterior UK home walls is likely to be travelling directly inward through the exterior brick or up from "rising damp"?
- How does %WME, easily measurable but not directly related to the moisture requirements of microorganisms, relate to A_w, which is more relevant to the water requirements of specific microorganisms (Ezratty et al., 2007)?
- How much of the moisture in damp houses that is directly related to adverse health effects would be discovered by one-time, widely spaced wall moisture measurements, given that building moisture can vary spatially and over time, that some relevant but inaccessible damp locations in buildings would never be identified by wall measurement, and that even brief but periodically repeated wetting that might not reach noteworthy thresholds can allow harmful levels of microbial growth over time?

Still, the studies reviewed here have demonstrated strong relationships between measured wall moisture and respiratory health in specific circumstances, suggesting that this approach has promise to identify at least some homes requiring investigation and remediation. Meanwhile, as this and similar approaches are developed and improved, researchers should continue working to identify the true dampness-related causal agents, microbial and other, that underlie the many positive research findings on dampness indicators and health.

Implications

The findings of this review suggest, at the least, that measured moisture of materials in buildings has promise for identifying some, although likely not all, dampness-related increased risks in homes, at least those with construction similar to those included in the two reviewed studies. However, confirmation of any specific applications is needed. Extrapolation to other wall materials, homes of different construction, or other moisture meters still requires further research to demonstrate any relationships. Perhaps the most useful research would focus on correlations of occupant health with A_w measurements of building moisture, which should be invariant across materials, although even documented A_w requirements for specific fungal growth are modified by temperature and the nutrient and chemical content of materials.

Recommendations

The IAQS/CDPH recommends work to develop evidence-based, health-protective, quantitative guidelines for indoor dampness and mold. This will likely require combining several approaches (Figure 2):
- Analyzing any additional existing epidemiologic data on measured moisture and health effects to better quantify relationships;
- Demonstration and validation of portable A_w sensors;
- Collection and synthesis of data, available and newly generated, on the equivalency of %WME and A_w in gypsum board and other common building materials, using different instruments;
- Conduct of additional epidemiologic studies in multiple countries to characterize relationships of A_w or %WME with key health effects;
- Continuation of other focused research on both subjective and objective assessments of indoor dampness and microbial exposures;
- Collecting and combining available information on the minimum A_w required for specific microbial species or groups of species, by specific material substrate

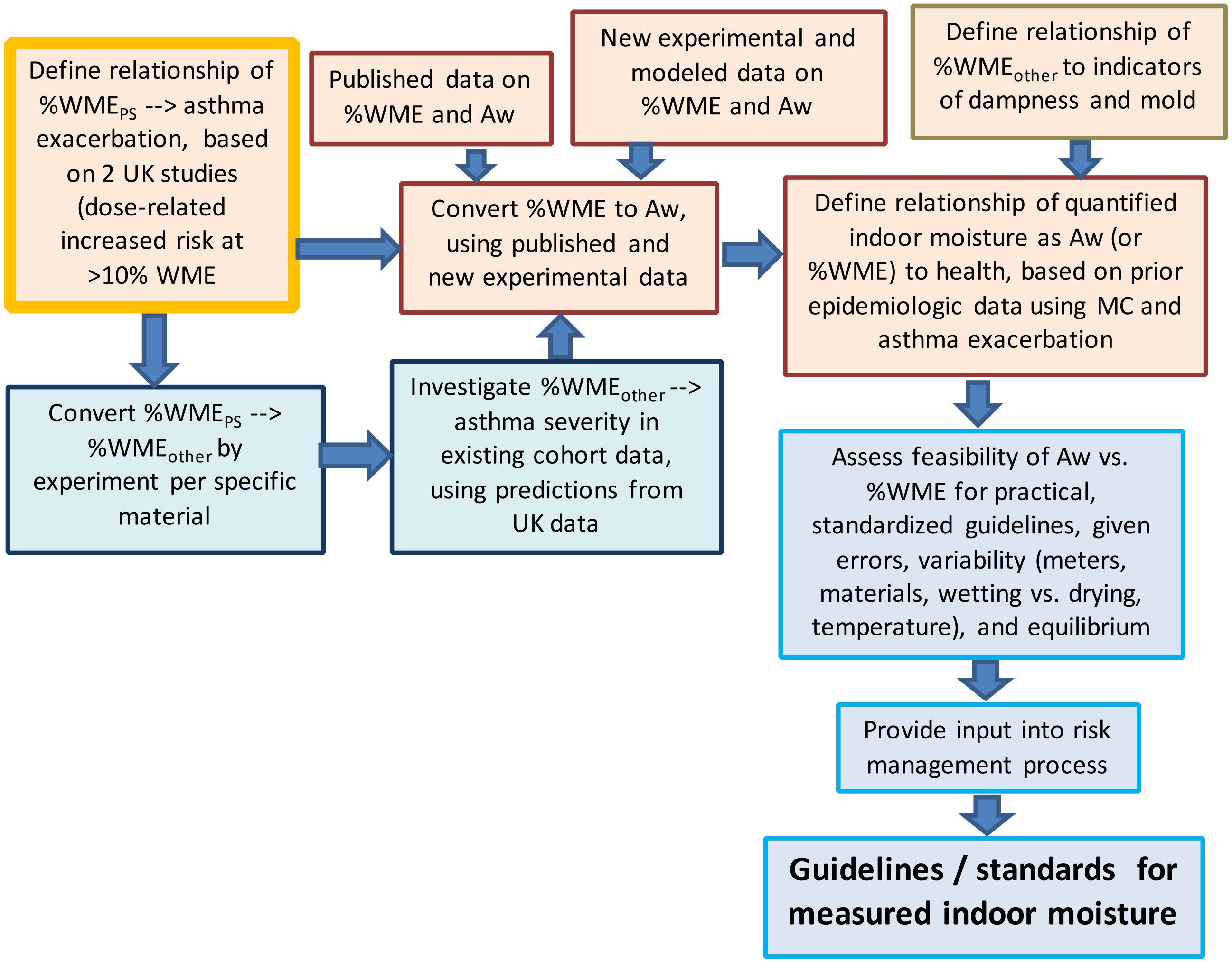

Figure 2. Developing moisture measurement as an evidence-based indicator of respiratory health risk. Abbreviations: A_w, water activity measured by Decagon^{TM}; other, other moisture meters; PS, Protimeter Surveymaster^{TM} moisture meter; UK, United Kingdom; WME, % wood moisture equivalent

- Conscious focusing of all these activities to provide key missing information needed for the goal of developing evidence-based, health-protective, quantitative guidelines for building-related dampness;
- Synthesizing all these types of information, first to generate initial quantitative health-protective guidelines on indoor dampness and mold, and then to guide additional research to provide information needed to refine the initial guidelines.

CONCLUSIONS

These findings on dose-related respiratory risks with increasing wall MC (as %WME), not previously synthesized, provide input into a process of developing evidence-based, health-protective, quantitative guidelines for indoor moisture. It is not yet clear if only A_w, or also %WME in specific materials, might be a suitable metric for broad health-protective guidelines related to indoor dampness. Additional research is needed on: %WME variation with different surface materials, temperatures, and instruments; the effects on microbial A_w requirements of material nutrients, chemical elements, pH, temperature, and prior wetting or microbial growth; and the identification of specific microorganisms or microbial communities as causal agents.

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