INSPECTOR-REPORTED AND OBJECTIVE MEASUREMENT OF INDOOR MOISTURE IN HOMES OF ASTHMATIC CHILDREN

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ABSTRACT
Epidemiological studies of indoor dampness and respiratory health frequently rely on survey-reported evidence or objective moisture measurements. In this investigation, the relationship between independent inspector reports and instrument measurements of moisture was assessed for 105 participants of the Fresno Asthmatic Children's Environment Study (FACES), a longitudinal cohort investigation of asthma and the environment. Only 4.8% of living rooms and 15.5% of bedrooms had inspector-reported signs of dampness. Homes with central or bedroom cooling systems had significantly lower moisture meter readings. There was no significant association between other housing characteristics and moisture readings, possibly due to the low frequency of "damp" homes in this population. Over the next several years, these homes will be resurveyed and additional homes will be inspected, allowing examination of multivariate associations between moisture, microbial contamination, dust mite and cockroach antigens, and short and long term measures of asthma morbidity.

INDEX TERMS
Moisture, Residences, Children, Asthma, Field Measurements

INTRODUCTION
The sharp increase in reactive airway disease in many countries around the world has contributed to a heightened interest in the health effects of the indoor environment. Numerous environmental agents, including indoor allergens, indoor and outdoor air pollutants and combustion products have been positively associated with an increased prevalence of childhood asthma.

The relationship between dampness or microbial growth in homes and adverse respiratory symptoms in children has been demonstrated in approximately 40 studies from a number of countries worldwide (Rylander and Etzel, 1999). An increase in respiratory morbidity among residents including airways infections (cough, wheeze, and asthma), was associated with building dampness in a recent summary of 61 peer-reviewed articles (Bornehag et al., 2001). Estimates ranged from OR 1.4–2.2. One study compared the adverse health effects of dampness to that of passive smoking (Strachan, 1988). A strong and consistent association also has been demonstrated between reported dampness and childhood respiratory symptoms and non-chest illnesses (Brunekreef et al., 1989).

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Most studies of the health effects of home dampness have relied on participant- or inspector-reported evidence of dampness or indoor humidity. A smaller number of studies have relied on objective measures of moisture. The review by Bornehag et al. (2001) of 61 epidemiological investigations of building dampness and health included ten studies with "objective" information on dampness. The "objective" measures in several of these studies were observational reports from home inspectors.

To date, few studies have compared independent inspector-reported evidence of moisture and moisture-meter readings. This report also examines relationships between indoor moisture measurements and home characteristic data collected during a survey of the homes of children participating in the Fresno Asthmatic Children's Environment Study (FACES).

METHODS

Families enrolled in FACES complete an interviewer-administered baseline interview that includes questions about the child's birth and health history, asthma symptoms and medication use. During a home visit the following month, a trained staff member completes a home characteristics survey while another inspector takes readings with a moisture meter in the living room and child's bedroom. As part of this survey, visual inspection of the presence of excess moisture or water damage is assessed. The data in this report were collected during home surveys conducted between November, 2000 and November, 2001 (105 homes). All homes were located in the Fresno or Clovis areas of California. Average temperatures in Fresno range from 57º F in the winter (December – February) to 96º F in the summer (June – August). The rainy season occurs from November to March (average precipitation = 1.7 inches), with little to moderate rainfall the rest of the year.

During the home visit, an inspector answered two questions related to potential indoor moisture problems:

(1) Do you see any evidence of moisture, leaks, water stains or condensation?
(2) Do you see mildew on the (a) Ceiling, (b) Walls (c) Window?

The inspector indicated the color, size and shape of the mildew where it was detected. A home was defined as "damp" if the response to the first question or any part of the second question was "yes." A similar designation of "home dampness" has been used in previous studies (Yang et al., 1997).

We hypothesized that some home characteristics would be associated with differing levels of moisture (e.g., use of a fireplace and venting of clothes dryers to the outside). Fireplace use in the home was defined as $\geq$3 days per month and was limited to homes surveyed in fall (September–November) and winter (December–February)(n=46). Fifty-one homes had a clothes dryer vented to the outside. We hypothesized that a window that could be opened in the child's bedrooms would be a source of damp outdoor air and that these homes would have higher moisture measurements. The presence of a dryer vented to the outside would be associated with differing levels of moisture. The impact of a cooling system (central or in-room) on indoor moisture also was evaluated (limited to homes surveyed March–August) as well as the effect of gas appliances (stove, dryer or water heater) and household crowding. Homes were defined as "crowded" if the ratio of the number of residents to the number of rooms, excluding bathrooms, was at least 1.0.

A second staff member used an Electrophysics moisture meter (model #CT100, London, Ontario) to measure wall moisture in the living room and the child's bedroom during the same home visit. The meter broadcasts electromagnetic radio waves and measure the rate at which the waves bounce back to the meter. The moisture in the wall material acts as a conductor for the electromagnetic radio waves. A wall with a higher moisture content corresponds to a higher moisture meter reading. The meter measures moisture content in the wall in which it was in contact on a scale of 0-30%. The moisture meter was placed, and a measurement was made on three walls in each room at the horizontal midpoint, 18-24 inches from the floor. Priority was given: (1) to external walls, (2) walls adjoining a bathroom, kitchen or laundry room, and (3) walls shared with a bedroom, the living room, or dining room.

The data for this report were analyzed using descriptive statistics of the distributions of maximum indoor moisture measurements. For each room, the median of measures throughout the year was calculated. The two rooms in each home were then categorized into low (median or below) or high (above the median) moisture categories. A large number of values occurred at the median and were assigned to the 'low' group. Housing characteristics relevant to indoor moisture were selected from the home survey and the association of these home characteristics to indoor moisture levels was assessed using the chi-square statistic. The same method was used to compare indoor moisture levels across seasons. All statistical analysis were performed using the SAS Statistical Analysis System (V6.12).

RESULTS

Complete moisture measurements were collected in 105 of the living rooms and in 103 of the child's bedrooms of the surveyed homes. Figure 1 displays a distribution of the moisture measurements in the living rooms and the child's bedrooms. The maximum, rather than the mean, of the three measurements was used to characterize indoor moisture. The median of the 105 maximum living rooms measurements was 9.0 (range 4.0–18.0), with an interquartile range (Q3-Q1) of 3.0. The median of the 103 maximum child's bedroom measurements was

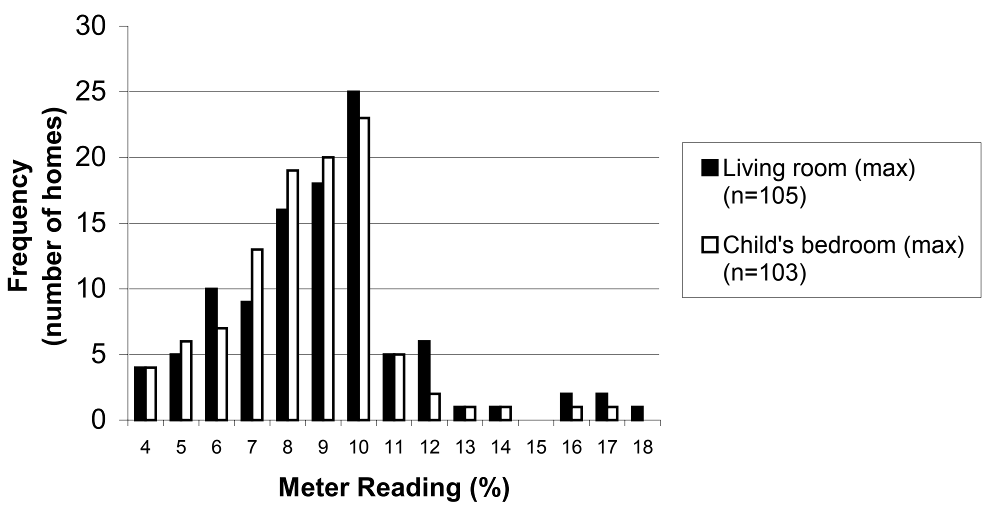

Figure 1. Distributions of highest moisture measurements

9.0 (range 4.0–16.0), with an interquartile range of 3.0.

The data from the home survey are summarized in Table 1. Seventy-six percent of the residences were single family homes and 18% were apartments. Signs of dampness in the living room were reported for only five homes (4.8%), three of which had readings in the "higher" moisture category. Inspector-reported dampness was noted for 16 (15.5%) of the child's bedrooms, which were evenly divided into the "higher" and "lower" moisture categories. There was a significant association between homes with lower moisture and a cooling system in the child's bedroom. The difference between the proportions of homes with a cooling system and lower moisture and those with higher moisture was 0.29 (95% CI 0.05-0.53).

Table 1 Frequency of housing characteristics by moisture category

	Living room (n=105) Moisture categories					Child's bedroom (n=103) Moisture categories				
	Lower # (%)		Higher # (%)			Lower # (%)		Higher # (%)		
	Yes	No	Yes	No	*p-value*	Yes	No	Yes	No	*p-value*
Dampness	2 (3)	60 (97)	3 (7)	40 (93)	0.375	8 (11)	62 (89)	8 (24)	25 (76)	0.094
Crowding	24 (39)	38 (61)	16 (37)	27 (63)	0.876	25 (36)	45 (64)	14 (42)	19 (58)	0.512
Open window in CB	59 (95)	3 (5)	40 (93)	3 (7)	0.643	67 (96)	3 (4)	31 (94)	2 (6)	0.696
Clothes dryer vented	6 (15)	33 (85)	1 (8)	11 (92)	0.535	6 (15)	33 (85)	1 (8)	11 (92)	0.535
Gas appliance	43 (69)	19 (31)	33 (77)	10 (23)	0.405	47 (67)	23 (33)	27 (82)	6 (18)	0.122
Fireplace use (Sept.-Feb.)	17 (61)	11 (39)	7 (39)	11 (61)	0.148	17 (55)	14 (45)	5 (38)	8 (62)	0.243
Cooling system (Apr.-Sept.)	31 (91)	3 (9)	22 (88)	3 (12)	0.69	33 (89)	4 (11)	12 (60)	8 (40)	0.01

Seasonal distribution of the moisture data for the two rooms is displayed in Figures 3 and 4. Season was not statistically significantly associated with moisture categories. However, using the annual median, 75% of the living rooms and child's bedrooms surveyed in the fall (September-November) fell into the "lower" moisture category.

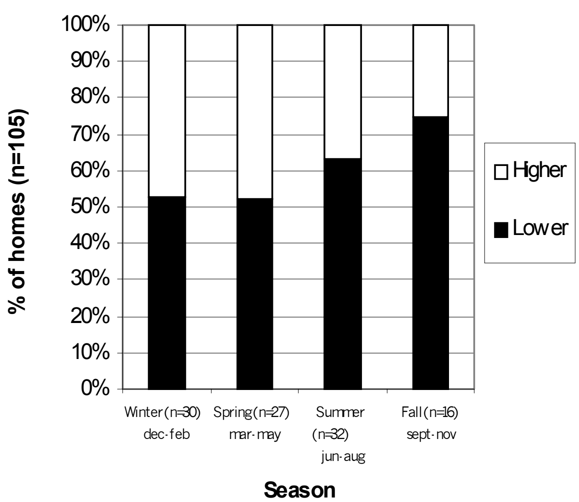

Figure 3 Moisture distribution by season in the living rooms

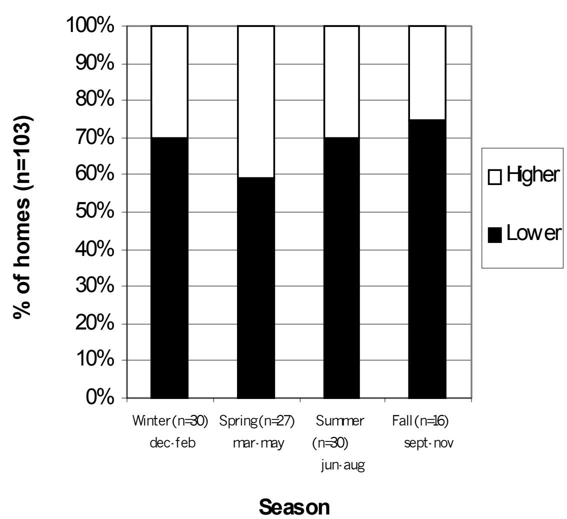

Figure 4 Moisture distribution by season in the child's bedrooms

DISCUSSION

The results presented in this report suggest an association between inspector-reported home dampness and objective measurement of indoor moisture in the child's bedroom. However, the relationship between these two methods is not strong, due in part to the small sample size and the low frequency of "damp" homes. The relatively small interquartile range of the moisture measurements in both rooms (Q3-Q1 = 3.0) may also obscure the relationship between objective measures and visual evidence of moisture in homes. As this study continues, several hundred more homes will be surveyed which will allow for the examination of multivariate associations between visible signs of moisture and microbial growth and moisture measurements across seasons and housing types.

Interpreting relationships between selected household characteristics and moisture was also impeded by the low frequency of certain home characteristics. However, the observed significant relationship between a cooling system and lower moisture in the child's bedroom may be due to a increase in the circulation and venting of air in the room when the cooling system is in operation. No significant association between frequent fireplace use and moisture in the home was observed. The additional heating from a fireplace could lower the moisture in a room or the moisture released during combustion could escape through the chimney. Although an association between home dampness and gas appliances was not observed, this may be explained by increased removal of indoor air when gas appliances are used (e.g., operation of a kitchen exhaust fan). All but five of the homes had a window that could be opened in the child's bedroom, and three of the five that did have a window had "higher" moisture readings.

Reporting bias should have played a negligible role in the results. All survey data were collected by field staff who have been trained to complete the home survey and collect moisture measurements using consistent and repeatable procedures. During the home visit, the first inspector noted visible evidence of moisture before the second inspector took the objective meter measurements. The information was recorded on separate data forms.

A previous study emphasized that occupant behavior affects the moisture level in homes and that neglecting to maintain ventilation and plumbing systems favors fungal growth (Dillon et al., 1999). A study that includes a home characteristics survey as well as a record of the occupant's home maintenance record may provide additional information useful in characterizing indoor moisture.

A number of different "dampness" indicators have been used, which may represent different moisture sources in buildings. Visible microbial contamination and condensation have been taken as indicators of high relative humidity whereas damp stains and other signs of water damage have been interpreted as evidence of leaks and moisture in the structure of a building (Bornehag et al., 2001). The objective measurement in our study was the water content of the wall materials rather than the relative humidity of the room air. Although the measurement of moisture in air is only an indirect indication of the water available to support microbial growth relative to the measurement of moisture in buildings materials (Brunekreef et al., 1989), a comprehensive study of indoor moisture conditions should include both.

CONCLUSIONS AND IMPLICATIONS

These findings do not support a strong association between inspector-reported, visible indicators of moisture and independent objective moisture measurements. The results do suggest an association between the presence of a cooling system in a child's bedroom and lower moisture-meter measurements. As this study continues, several hundred additional homes will be surveyed and each home will be visited in multiple seasons. The resulting data will allow the examination of multivariate associations between moisture and microbial growth across seasons and housing types. We will continue to examine the association between these two methods of assessing moisture and, eventually, their relationships to indoor biological agents and short and long term measures of asthma morbidity.

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