

Low home ventilation rate in combination with moldy odor from the building structure increase the risk for allergic symptoms in children

Abstract There are consistent findings on associations between asthma and allergy symptoms and residential mold and moisture. However, definitions of 'dampness' in studies are diverse because of differences in climate and building construction. Few studies have estimated mold problems inside the building structure by odor assessments. In a nested case-control study of 400 Swedish children, observations and measurements were performed in their homes by inspectors, and the children were examined by physicians for diagnoses of asthma, eczema, and rhinitis. In conclusion, we found an association between moldy odor along the skirting board and allergic symptoms among children, mainly rhinitis. No associations with any of the allergic symptoms were found for discoloured stains, 'floor dampness' or a general mold odor in the room. A moldy odor along the skirting board can be a proxy for hidden moisture problem inside the outer wall construction or in the foundation construction. There are indications that such dampness problems increase the risk for sensitization but the interpretation of data in respect of sensitization is difficult as about 80% of the children with rhinitis were sensitized. Furthermore, low ventilation rate in combination with moldy odor along the skirting board further increased the risk for three out of four studied outcomes, indicating that the ventilation rate is an effect modifier for indoor pollutants.

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Practical Implications

This study showed that mold odor at the skirting board level is strongly associated with allergic symptoms among children. Such odor at that specific place can be seen as a proxy for some kind of hidden moisture or mold problem in the building structure, such as the foundation or wooden ground beam. In houses with odor along the skirting board, dismantling of the structure is required for an investigation of possible moisture damage, measurements, and choice of actions. In homes with low ventilation in combination with mold odor along the skirting board, there was even a higher risk of health effects. This emphasizes the need for the appropriate remediation as this is an ever increasing problem in poorly ventilated houses that are damp.

Introduction

The prevalence of childhood asthma and allergy has increased during the last decades (Beasley

et al., 2003; Ellwood et al., 2005). However, recent studies have reported that the prevalence of asthma could have reached a peak level even though symptoms of atopic dermatitis still may be on

rise (Grize et al., 2006; Kälvesten and Bråbäck, 2008).

People in Western countries, children in particular, spend more than 90% of their time indoors (Leech et al. 2002) meaning that the indoor environment probably plays a significant role for the origin of respiratory and allergic disease. Focus have, in particular, been on exposure to 'dampness' and molds in buildings in which a number of studies have been associated with asthmatic and allergic symptoms, although causative agents for such health effects are still unknown, but both biological and chemical substances are suspected (Bornehag et al., 2001, 2004a; Institute of Medicine, 2004, Peat et al., 1998). As much as 30–50% of respiratory health effects have been related to moisture-related problems in homes (Fisk et al., 2007). Two earlier multidisciplinary reviews (NORDDAMP and EUROEXPO) of the scientific literature on dampness in buildings and health concluded that most of the studies were of cross-sectional origin and based on self-reported dampness and self-reported health. Only a few studies included independent data with inspector observed signs of dampness and clinical examination of health effects by a physician (Bornehag et al., 2001, 2004a). One problem is the wide definition of 'dampness' used in the studies, because of differences in outdoor climate, building construction, heating and use of air condition, and type of ventilation technique. In well-insulated buildings in cold climates (as in Scandinavia), visible mold on indoor surfaces is rare because of a combination of high surface temperature and low relative humidity. Hence, dampness and mold problems in such dwellings must be investigated with other methods than ocular inspections.

The objective of this study has been to evaluate associations between doctor-diagnosed asthma and allergic diseases in pre-school children and moisture-related problems in the children's homes observed by professional inspectors. Furthermore, a more nuanced description of moisture problems with grade of severity and type of observation using both visible signs and odor assessments has been explored.

Method

This study is a part of the Dampness in Buildings and Health (DBH)-study on indoor environmental factors in homes and its relation to asthma and allergy among pre-school children and their families in the county of Värmland, Sweden.

The first phase of the DBH-study, a cross-sectional questionnaire study of 10,851 children, was carried out in March 2000 (Bornehag et al., 2005b). The phase of the survey, DBH-phase II, was a nested case-control study with 198 cases and 202 healthy referent children between 3 and 8 years of age.

The inclusion criteria for the cases in DBH-phase II were:

- In the DBH-phase I questionnaire reports of at least two symptoms of 'wheezing during last 12 months without a cold', 'rhinitis during last 12 months without a cold' and 'eczema during last 12 months'.

In the follow-up questionnaire one and a half years later they had to:

- Report at least two of three possible symptoms.

Inclusion criteria for the controls were:

- No symptom in the first questionnaire, and
- no symptoms in the follow up questionnaire.

For both groups they had to:

- Agree to cooperate,
- not have rebuilt their homes because of moisture problems and
- not have changed residence since the first questionnaire.

All children with at least two symptoms in the first questionnaire were invited to the case-control study, ($n = 1056$ corresponding to 9.7% of the total population). In the first questionnaire 5303 (48.9%) reported no airway, eye, nose or skin symptoms. Of these, 1100 children were randomly selected and invited to co-operate in the case-control study. This process ultimately yielded 198 cases and 202 controls. A more detailed description of the selection procedure and the influence of potential selection biases are described in (Bornehag et al., 2006).

The medical and technical investigations in DBH-phase II were carried out from October 2001 until April 2002. Three teams with a physician and a skilled nurse examined the 400 children and clinical samples were taken. The physician specifically diagnosed signs of asthma, rhinitis, and eczema. The procedure and results of the medical examinations are described elsewhere (Hasselgren, 2005). Blood samples were drawn from 387 children and screened for sensitization to common allergens, (Phadiatop[®]; Pharmacia & Upjohn Diagnostics, Uppsala, Sweden) and the sensitized children were further tested for specific IgE (RAST) for cat, dog, horse, birch-, mugwort- and timothy grass pollen, house dust-mites (*Dermatophagoides pteronyssinus*, *Dermatophagoides farinae*), and mold (*Penicillium*, *Cladosporium*). Information on parental smoking and any atopic symptoms was given in an interview by the doctor at the time of the clinical examination.

During the same time period as the health examinations (within 10 days), six inspectors visited the children's homes. The 400 children lived in 390 homes since there were 10 pairs of siblings. One inspector investigated two houses per day. All the inspectors were non-smokers and they were blinded in regard to

the case-control status of the children and instructed not to discuss the health of the child and family with the parents. A parental questionnaire on e.g., cleaning habits was obtained during the inspection.

The dwellings were inspected without any destructive methods or dismantling of structures. The investigators noticed type of constructions, type of materials in the building, and type of installation systems, etc., using a standardized room-by-room protocol. Due to time limits crawlspaces and cold attics were not inspected. Samples of dust and air were collected in the children's bedroom and the living room for analyses of chemical and biological compounds and measurements of ventilation rate (air changes per hour, h^{-1}), temperature and relative humidity were made (Bornehag et al., 2004b). Ventilation rates of the entire home and of the bedroom of the child were measured during 1 week with a passive tracer gas method (Bornehag et al., 2005a, Nordtest 1997).

Four indices of dampness severity were calculated for each home regarding to the inspector's observation:

Moldy odor: First impression of moldy, earthy or musty odor when entering the home and/or moldy odor in at least one room.

Moldy odor along the skirting board in at least one room: The inspectors got down on their knees to be able to 'sniff' areas near the skirting board in at least one position in every room (moldy, earthy or musty odor).

Discoloured 'damp' stains in at least one room: Visible spots of mold, stains of dampness or discoloured stains on walls or ceiling.

Floor dampness in at least one room: Black areas on parquet flooring or bubbly, loosening floor covering material like vinyl or linoleum.

Each home was scored on a three level scale for each index: grade 0 (No remarks), grade 1–2 (Mild) and grade 3 (Severe). The original data was scored in four grades (0, 1, 2 or 3), but in the analyses, grade 1 and grade 2 were put together due to a vague distinction between them. A home was classified into one of the three grades based on the highest grade in at least one room, described above.

Statistical methods

Health data from the clinical examinations were analyzed as the dependent variable against inspectors' observations of mold, moisture-related problems, and moldy odor in the dwellings. Chi-square tests were used for comparisons between building characteristics and dampness indexes. Trends in the data were tested with linear by linear associations. Odds ratios (OR) were estimated in conditional logistic regression analyses with 95% confidence intervals. In multiple regression analyses, adjusted odds ratios (AOR) were calculated with adjustments for gender (male vs. female), age of

the child (3–4, 5–6, 7–8 years of age), smoking parent (yes vs. no), asthma, and allergy in family (asthma, rhinitis or eczema in at least one parent vs. no such symptoms), type of building (single-family house, row house, multi-family house), and construction period (before 1960, 1961–1983, 1984 to present). In further models, adjustments were additionally made for phthalate degraded products in settled dust in the child's bedroom, (DEHP, di(2-ethyl-hexyl) phthalate and BBzP, (butyl benzyl phthalate) – two components often used as plasticisers in consumer products), and for ventilation rate of the home (above vs. below median). These have been associated with symptoms in earlier publications from this study (Bornehag et al., 2005a, Bornehag et al. 2004d). Student's *t*-test was used to compare ventilation rate and indexes of dampness. A *P*-value of <0.05 was used as an indication of significance. The study was approved by the research ethic committee in Örebro, Sweden.

Results

Demographic data and building characteristics of the homes of the 400 cases and controls are presented in Table 1. The parents of the case children reported allergic symptoms of their own twice as often than the parents of the controls. Case children had more often a smoking parent than control children, but the difference was not significant. In the relatively few families where both parents were smokers, all children were diagnosed as cases ($n = 11$). Control children lived more often in old houses (constructed before 1940) whilst cases more often lived in houses from the 1970s.

A general finding was that moldy odor indoor was more commonly experienced by the inspectors than visible signs of dampness (discoloured 'damp' stains and floor dampness). All types of moisture problems were reported more frequently in single-family houses and row houses, as well as in buildings from the 1960s and 1970s and in buildings with natural ventilation.

A mild or severe moldy odor was detected in at least one room of 39.2% of the dwellings, and in almost half of the dwellings (47.4%) a mild or severe moldy odor along the skirting board was found. Discoloured stains were observed in 24.6% of the dwellings; only 3.8% of these were regarded as severe. Of 96 dwellings indexed as 'discoloured stains' only six had visible mold growth (mild grade of severity) on the wall. Signs of discoloration and loosening of flooring material, parquet or vinyl/linoleum flooring was uncommon (7.4%) and only four houses were considered to have severe signs of floor dampness.

A mild or severe moldy odor was more frequently observed in single family and row houses compared with multi-family houses (42.5 vs. 13.6%; Chi-squared test: $P < 0.001$) as well as mild or severe discoloured

Table 1 Demographic data and home characteristics for the 400 children

	Controls, <i>n</i> = 202 (%)	Cases, <i>n</i> = 198	<i>P</i> -value ^a
Sex			
Boys	114 (56.4)	113 (57.1)	0.898
Girls	88 (43.6)	85 (42.9)	0.898
Age			
2–4	74 (36.6)	77 (38.9)	0.642
5–6	80 (39.6)	85 (42.9)	0.499
7–8	48 (23.8)	36 (18.2)	0.171
Smoking parent	30 (14.9)	40 (20.2)	0.159
Atopic symptom in at least one parent	87 (43.1)	161 (81.3)	<0.001
Sensitized for common allergen	23 (11.8)	92 (47.9)	<0.001
Frequency of wet cleaning the floor in child's bedroom ^b			
Two times per week or more often	3 (1.5)	7 (3.7)	
One time per week	44 (22.2)	70 (36.6)	
Once a fortnight	49 (24.7)	51 (26.7)	
Once a month or less	102 (51.5)	63 (33.0)	0.001 ^c
Type of building			
Single-family house (SH)	172 (85.1)	161 (81.3)	0.304
Row house (RH)	11 (5.4)	12 (6.1)	0.792
Multi-family house (MH)	19 (9.4)	25 (12.6)	0.303
Construction period			
Before 1940	67 (33.2)	47 (23.7)	0.037
1941–1960	35 (17.3)	37 (18.7)	0.723
1961–1970	25 (12.4)	28 (14.1)	0.603
1971–1983	44 (21.8)	63 (31.8)	0.023
1984–Present	31 (15.3)	23 (11.6)	0.275
Type of ventilation system			
Natural	142 (70.3)	124 (62.6)	0.104
Exhaust	37 (18.3)	56 (28.3)	0.018
Balanced	23 (11.4)	18 (9.1)	0.449
Type of foundation ^d			
Basement	69 (40.1)	61 (37.4)	0.613
Crawlspace	58 (33.7)	42 (25.8)	0.137
Concrete slab on the ground	45 (26.2)	60 (36.8)	0.069

^aPearson chi-square test.^bDwellings with textile wall to wall carpet in the child's bedroom excluded (*n* = 4).^cTested with linear by linear association for trends.^dData available only for single-family houses and row houses. Other type of foundation, *n* = 15 and missing information, *n* = 6.

stains (26.3 vs. 11.4%; *P* = 0.030) and a severe moldy odor along the skirting board (17.3 vs. 6.8%; *P* = 0.074). Buildings erected between 1960 and 1983 were more often affected by a mild or severe moldy smell and moldy odor along the skirting board compared with buildings from other periods (49.0 vs. 32.6% *P* = 0.001 and 58.0 vs. 42.5%; *P* = 0.003). Discoloured 'damp' stains were more commonly observed in buildings with natural ventilation compared to buildings with mechanical ventilation systems (30.0 vs. 14.3%; *P* = 0.001) and the same was observed for moldy odor, (42.8 vs. 32.3%; *P* = 0.045). A mild or severe moldy odor along the skirting board was less often observed in houses with a balanced ventilation, in contrast to buildings with natural or mechanical exhaust systems (22.5 vs. 51.7%; *P* < 0.001), and most common in houses with exhaust ventilation systems (57.0 vs. 47.1%; *P* = 0.067). Single-family houses and row houses with a crawlspace or a basement were more often affected by a mild or

severe moldy odor than those with a concrete slab on the ground (46.4 vs. 33.9%; *P* = 0.026). However, severe moldy odor along the skirting board was more often observed in houses with a concrete slab on the ground (22.0 vs. 14.4%; *P* = 0.075) compared to other types of foundation.

A moldy odor along the skirting board and severe moldy odor in indoor air were significantly associated with a low ventilation rate. Associations between moisture problems and building characteristics are further presented elsewhere (Hägerhed Engman, 2006; Hägerhed-Engman et al., in press).

Associations between the dampness indexes and health of the children are presented in Table 2. A significant dose-response relationship for unadjusted proportions was found between severity of moldy odor along the skirting board and doctor-verified case status, rhinitis, and eczema. A moldy odor in the dwelling and floor dampness were not associated with any of the tested health outcomes. Discoloured 'damp' stains were negatively associated with health outcomes, but in general not significantly so.

Earlier in this study, associations between a low ventilation rate and allergic symptoms have been reported (Bornehag et al., 2005a). Furthermore, we have shown a strong association between phthalates in settled dust (DEHP, BBzP) and doctor diagnosed asthma, rhinitis, and eczema (Bornehag et al., 2004c). When adjusting for ventilation rate (below or above median: 0.34 h⁻¹) and for concentration of phthalates in settled dust (below or above median concentration) in analyses, the results reported in Table 2 remained valid (data not shown), and a low ventilation rate and a high concentration of phthalates in dust remained associated to the health outcomes as reported earlier.

In Table 3, the association between the health outcomes and a combination of ventilation rate (above or below median: 0.34 h⁻¹) and moldy odor along the skirting board is presented. The highest odds ratios for case children were found in homes with a low ventilation rate in combination with a moldy odor along the skirting board. The strongest association was found for rhinitis.

Sensitization (IgE in blood) was, as expected, more commonly found among case children (48%) than among controls (12%). When comparing case children with and without sensitization (*n* = 92 vs. *n* = 100), moldy odor along the skirting board (mild or severe) was more frequently found among sensitized cases (62% vs. 45.0%, *P* = 0.019).

Two of the six inspector's observations differed from the others, (inspector C and E). Inspector C observed considerably more often moldy odor and moldy odor along the skirting board than the five others, and inspector E did not report any such odor in any house. In analyses where inspector C's data were excluded, the associations between moldy odor and moldy odor

Table 2 Associations between four dampness indexes and different health outcomes

Degree of severity, <i>n</i>	Controls, <i>n</i> (%)	Cases status		Asthma, <i>n</i> = 121		Rhinitis, <i>n</i> = 99		Eczema, <i>n</i> = 129	
		<i>n</i> (%)		<i>n</i> (%)		<i>n</i> (%)		<i>n</i> (%)	
		OR	AOR ^a	OR	AOR ^a	OR	AOR ^a	OR	AOR ^a
Moldy odor	122 (60.4)	1	1	1	1	1	1	1	1
Mild	45 (22.3)	1.06 (0.66–1.72)	1.07 (0.62–1.84)	1.10 (0.64–1.90)	0.99 (0.54–1.84)	1.48 (0.84–2.59)	1.78 (0.92–3.45)	1.20 (0.71–2.03)	1.26 (0.69–2.30)
Severe	35 (17.3)	0.90 (0.52–1.55)	0.83 (0.44–1.56)	0.80 (0.42–1.53)	0.57 (0.27–1.26)	0.89 (0.44–1.78)	1.07 (0.46–2.46)	0.82 (0.43–1.54)	0.76 (0.36–1.61)
<i>P</i> -value ^b	0.877			0.698		0.302		0.573	
Moldy odor skirting along the board	95 (48.0)	1	1	1	1	1	1	1	1
Mild	60 (29.7)	1.30 (0.84–2.03)	1.38 (0.83–2.28)	1.29 (0.78–2.14)	1.30 (0.73–2.29)	1.75 (1.01–3.00)	2.23 (1.17–4.24)	1.59 (0.97–2.62)	1.86 (1.04–3.30)
Severe	26 (12.9)	1.83 (1.04–3.22)	1.69 (0.88–3.26)	1.56 (0.81–3.00)	1.28 (0.60–2.73)	2.29 (1.16–4.49)	2.45 (1.08–5.54)	1.96 (1.04–3.69)	1.93 (0.91–4.12)
<i>P</i> -value ^b	0.029			0.142		0.007		0.017	
Discoloured 'damp' stains	148 (73.3)	1	1	1	1	1	1	1	1
Mild	44 (21.8)	0.83 (0.51–1.35)	0.86 (0.50–1.48)	0.89 (0.51–1.56)	0.86 (0.47–1.60)	1.22 (0.69–2.13)	1.39 (0.73–2.67)	0.67 (0.37–1.19)	0.64 (0.34–1.20)
Severe	10 (5.0)	0.48 (0.16–1.43)	0.45 (0.13–1.55)	0.32 (0.07–1.47)	0.28 (0.5–1.52)	0.21 (0.03–1.64)	0.37 (0.04–3.43)	0.28 (0.06–1.30)	0.30 (0.06–1.57)
<i>P</i> -value ^b	0.158			0.205		0.604		0.036	
Floor dampness	186 (92.1)	1	1	1	1	1	1	1	1
Mild	14 (6.9)	0.87 (0.39–1.92)	0.87 (0.35–2.12)	0.70 (0.26–1.87)	0.82 (0.28–2.42)	0.87 (0.32–2.33)	1.16 (0.36–3.76)	0.66 (0.25–1.76)	0.78 (0.26–2.34)
Severe	2 (1.0)	1.01 (0.14–7.25)	1.12 (0.13–9.79)	0.82 (0.07–9.10)	0.82 (0.05–12.33)	1.01 (0.09–11.29)	1.58 (0.10–26.14)	1.54 (0.21–11.06)	1.88 (0.20–17.29)
<i>P</i> -value ^b	0.791			0.512		0.830		0.747	

^aAdjustments for sex, age, smoking in family, asthma, allergy and/or eczema in family, construction period, type of building.

^bTested with linear by linear association for trends (crude analysis).

along the skirting board and the health outcomes decreased somewhat but remained roughly the same, while in the analyses where inspector E's data were excluded the association became somewhat stronger. This was also the case when both inspectors C's and E's data were excluded (data not shown). There were no significant differences in the distribution of cases and controls, or type of buildings between the different inspectors, and the ORs for health vs. dampness indexes did not differ between the inspectors. Hence, in the results presented here, all inspectors' observations are included in the analyses.

Discussion

The dwellings were more often affected by a moldy odor in the room or along the skirting board than of visible mold or discoloured 'damp' stains. Almost half of the houses had mild or severe moldy odor or moldy odor along the skirting board while one-fourth had discoloured 'damp' stains according to the inspectors. To detect the amount and cause of a moisture problem within the construction, dismantling of the construction is needed for inspection and measurements of humidity and mold growth. However, to choose locality for such destructive measures, investigators working in this field often use the method of sniffing near the skirting board in combination with other techniques. Under normal conditions, the negative air pressure at floor level indoor facilitates this type of odor assessment.

The frequencies of mold and dampness varies a lot between different studies; in the NORDDAMP review between 4 and 75% (Bornehag et al., 2001) and in ECRHS-study including 38 European study centres between 5 and 55% (Zock et al., 2002). Dampness is often described as one or more of the following indications; visible mold, damp stains, condensation on windows and/or walls, high relative humidity in the air, moldy odor, stuffy odor, need of repair, flooding or water damage (NORDDAMP). The important difference is that some of the indications are because of high moisture content in the indoor air which may give rise to condensation and mold growth on cold indoor surfaces while others are signs of hidden moisture problems in the building structure.

In the sub-arctic climate of Scandinavia, with a heating season from October to April, the relative humidity indoors can be low (<20%) for several months during the winter season. In combination with well-insulated constructions, the temperature on indoor surfaces is close to the room temperature and the dew point temperature is low which limits the risk for surface condensation and visible mold. However, modern building structures in these climates are often heterogeneous constructed with multi layer structure containing wood, insulation, vapour barrier, and

Table 3 Association between different health outcomes and combinations of moldy odor along the skirting board and ventilation rate in the home

	No moldy odor at the skirting board (no remarks)						Moldy odor at the skirting board, (mild or severe)						<i>P</i> -value ^b
	High ventilation rate (above median) (Ref), <i>n</i> = 114			Low ventilation rate (below median), <i>n</i> = 92			High ventilation rate (above median), <i>n</i> = 84			Low ventilation rate (below median), <i>n</i> = 106			
	%	OR	AOR ^a	%	OR	AOR ^a	%	OR	AOR ^a	%	OR	AOR ^a	
Case status	38.6	1	1	51.1	1.66 (0.95–2.90)	1.42 (0.76–2.65)	53.6	1.84 (1.04–3.25)	1.52 (0.80–2.90)	58.5	2.24 (1.31–3.85)	2.39 (1.27–4.50)	0.003
Asthma	30.7	1	1	38.4	1.41 (0.75–2.65)	1.20 (0.59–2.46)	44.3	1.80 (0.95–3.38)	1.44 (0.71–2.94)	41.3	1.59 (0.85–2.97)	1.60 (0.77–3.32)	0.093
Rhinitis	20.5	1	1	31.8	1.82 (0.87–3.78)	1.68 (0.73–3.84)	40.0	2.59 (1.27–5.31)	2.52 (1.11–5.76)	43.6	3.01 (1.52–5.96)	4.40 (1.92–10.12)	0.001
Eczema	26.3	1	1	39.2	1.80 (0.94–3.47)	1.43 (0.68–3.02)	46.6	2.44 (1.28–4.67)	2.13 (1.01–4.48)	48.2	2.61 (1.40–4.87)	3.14 (1.48–6.67)	0.002

^aAdjusted odds ratio: Adjustments made for sex, age, smoking in family, asthma, allergy and/or eczema in family, construction period.

^bTrend analysis made by linear by linear analysis.

gypsum board. The structure is energy efficient but any moisture, e.g. trapped moisture from the building process, leakage or moisture-convection are risk factors for mold growth within the construction, compared to solid constructions of concrete or bricks. A moldy odor along the skirting board can consequently be a proxy for hidden moisture problems inside the construction.

In 103 dwellings, there was no concordance between moldy indoor odor and moldy odor along the skirting board. A moldy odor along the skirting board can be seen as an indication of moisture damages in the buildings structure, but a moldy odor in general can be due to several factors in the building; not only odor from the attic, local spots of damages as in a closet or kitchen, but also odor from food, dirt, pets, fruit, fire wood or pot plants. Furthermore, the assessment of moldy odor indoor could have been confused with other odors in the dwelling such as bad, stuffy or musty odor. One can speculate on why a moldy odor along the skirting board i.e. odor from the building structure was strongly associated to rhinitis and to some extent asthma and eczema, while a moldy odor in the indoor air was not. This could be a chance finding, or due to that a moldy odor along the skirting board is a proxy for something truly health relevant. Moisture-related problems in Swedish buildings are often located to the foundation structure or the lower part of a building as these sites are exposed to moisture both from the ground, and from rain and snow and built in moisture. Microbiological or chemical degradation products from affected building material from these parts of the construction may play a role both for odor problems and studied health effects.

Studies with inspectors' assessment of moldy odor in residents are few and others, often visible definitions of dampness, are more often used. In a Finnish study of 363 homes with 121 asthmatic children, inspectors observed moldy odor in 8% of the dwellings (Haverinen-Shaughnessy et al., 2005), with a non-significant association to asthma (OR = 1.91 CI = 0.81–4.49) (Hyvärinen et al., 2002). In our study, the frequency

of severe moldy odor in at least one room was double as high (16%) as in the study from Finland but was not associated with either asthma or allergy. In fact, the prevalence of symptoms were in general lower in the group with severe moldy odor compared with the group with no remarks; however, the differences were not significant. In a Chinese study of student dorms, where they used the same inspection-sheet as in this DBH-study, moldy odor observed by an inspector was not associated with asthmatic and allergic symptoms, while such odor reported by the students in a questionnaire strongly associated with health effects (Sun et al., 2007). The latter has been found in this DBH-study as well as in another study in Bulgaria using the same protocol consider that inspectors role as 'gold standard' might be discussed (Hägerhed Engman, 2006; Naydenov et al., 2008).

Discoloured 'damp' stains were not associated with symptoms, in contrast to most other studies. However, in the Chinese study by Sun et al. (2007), visible spots of dampness observed by inspectors were not associated with health effects among the students. In our study, the discoloured stains often smaller than 15 × 15 cm, were not spots of mold growth because of surface condensation as that only was observed in six dwellings (bathrooms excluded). The discoloured stains in our study were more likely signs of earlier water-leakage from e.g. radiators, rain or watering the plants and identified as a water mark on the wallpaper. According to the inspectors grading of these stains, they were in most cases not regarded to affect the indoor air quality, i.e. judged as 'mild' grade of severity. Furthermore, there was an association between a low ventilation rate and moldy odor (both in indoor and along the skirting board) but no association between a low ventilation rate and discoloured stains were found. This too indicates that damp stains in this study not were due to high indoor air humidity. The negative association between discoloured stains and health might also be caused by a more rigorous repair activity among parents with a case child.

Indications of a moisture problem in the floor structure 'floor dampness' were not associated with any of the examined health outcomes. 'Severe' moisture problems in the floors were only found in two homes. There are consequently doubts whether this index really can be used as a sign of moisture problems in the floor.

We found an association between sensitization among cases and moldy odor along the skirting board. However, it is not possible to say if this association is driven by the stronger association between moldy odor along the skirting board and rhinitis where 81% of the children with rhinitis were IgE positive while concomitantly about 50% of the children with asthma and/or eczema were IgE positive. The issue whether a moldy odor along the skirting board is a risk factor for sensitization or not, cannot be further explored in our data which makes this an open question. On the other hand, there are reports indicating a relationship between dampness and sensitization. (Verhoeff et al., 1995) compared sensitized asthmatic children with non-sensitized controls and found significantly greater odds ratios as when comparing non-sensitized asthmatics with non-sensitized controls for observed dampness and mold. They concluded that home dampness might lead not only to sensitization to house dust-mites and molds but also to atopy in general. A study from Finland studied the association between exposures to molds in a moisture-damaged school and increased IgE sensitization among the school children compared to a control school (Savilahti et al., 2001). Because only one child had positive IgE to molds they concluded that health effects of moisture-damaged buildings are not caused by IgE-mediated allergy to microorganisms, but more likely explained by other mechanisms associated to mold exposure.

As low ventilation rate and a moldy odor along the skirting board were correlated with each other and both of them were associated with asthma and allergy among the children there is a risk for confounding. To investigate this possible bias, the association between moldy odor along the skirting board and health outcomes were tested in both adjusted and stratified analyses. When adjusting for ventilation rate (in quartiles) in the multiple logistic models, the association between a moldy odor along the skirting board remained (Table 2). Also, the analyses presented in Table 3 show that the association between health outcomes and moldy odor along the skirting board is higher in the group with low ventilation rate compared with high ventilation rate. This means that our results cannot be explained by low ventilation rate only. But low ventilation rate seems to reinforce the association between health and moldy odor along the skirting board. We found a significantly increased risk for asthma and allergy when combining a low ventilation rate and moldy odor along the skirting board in the

analyses. This result support the findings reported by a Norwegian study (Öie et al., 1999). Öie et al. concluded that a low ventilation rate might strengthen the effect of moisture problems in the building and they found higher risk of bronchial obstruction among children in the group with lower air change rate in combination with dampness, environmental tobacco smoke, presence of textile wall and plasticizer-containing surfaces. These two studies are supporting the hypothesis that ventilation rate is an effect modifier for indoor pollutants.

Another possible confounder is the wet cleaning frequency in the homes, as families of case children wet cleaned more frequently and there was a weak association between wet cleaning and moldy odor along the skirting board. However, adjusting and stratifying data for cleaning habits did not change the associations between moldy odor along the skirting board and asthma/allergy reported in Table 2 (data not shown).

The inspectors in this study had no information about the health status of the child or questionnaire reports on dampness and they were instructed not to discuss any of these matters with the parents. This means that there is a limited risk for observation bias as a result of the knowledge of the case-control status of the child. However, as the inspectors have experience of making investigations in damp buildings, there is a risk of bias when an inspector enters certain types of buildings. In such a house an inspector may be likely to make every possible effort to find moldy odor or other signs of dampness. Yet, the pre-established checklist was followed in all houses and sniffing along the skirting board in each room was made for all included dwellings which partly reduced the risk of such bias. Two of the inspectors differed from the others regarding the frequency of observations of moldy odor and moldy odor along the skirting board (Engman et al., 2007). However, the point estimates did not change significantly when these two inspectors were excluded from the analyses.

The subjective measure of odor by the human nose has some disadvantages; the sensitivity as seen in this study may be different for different people (even if they are trained inspectors) and an odor assessment is always subjective. Furthermore, microbes smell different depending on species, phase of life cycle, temperature, and kind of affected building material. Some objective measurements for detecting hidden mold has been tested such as microbially produced volatile organic compound, electronic nose, and special-trained dogs, but none of these methods have been shown to correlate with either inspectors observations on dampness or health effects (Kauhanen et al., 2002; Schleibinger et al., 2005; Vinaixa et al., 2004).

Searching for moldy odor along the skirting board may be a fast and cheap method to be used as a proxy for hidden moisture problems in the building structure

without using destructive and expensive dismantling, at least in cold climates. Our results support the hypothesis that odor from microbiological and/or chemical degradation of building material can be transported into the indoor environment and increase the risk for allergic symptoms among children as well as sensitization. However, we do not know which health-relevant exposures that are in action and both chemical microbiological agents are suspected. Further studies should develop methods of detecting hidden moisture damages inside the building structure and associations between smell and specific agents in indoor air and in dust ought to be explored. Another important finding was that low ventilation rate increased the risk associated with mold odor at skirting board for three of

four outcomes show that the impact of these risk factors can be underestimated when both are not studied together.

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