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Asthma symptoms in relation to measured building dampness in upper concrete floor construction, and 2-ethyl-1-hexanol in indoor air

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SUMMARY

SETTING: Asthma symptoms in adults in relation to the indoor environment.

OBJECTIVES: To study the relationships between current asthma symptoms (wheeze or attacks of breathlessness) and the indoor environment and dampness in hospitals.

DESIGN: A study among personnel (n = 87) in four geriatric hospitals in winter. Indoor air pollutants, dampness in the concrete floor, and allergens in settled dust were measured. Multiple logistic regression analysis was applied, adjusting for age, sex, atopy, and dampness in the participants' own dwellings.

RESULTS: Current asthma symptoms were reported by 17%, and 8% had doctor's diagnosed asthma. Asthma symptoms were more common (adjusted odds ratio = 8.6; 95% confidence interval 1.3–56.7) in two buildings with signs of dampness-related degradation of di(ethyl-hexyl)-phthalate (DEHP) in polyvinyl chloride (PVC) floor material, detected as presence of 2-ethyl-1-hexanol (2–32 $\mu g/m^3$) in indoor air (CAS nr 104-76-7). Asthma symptoms were related to higher relative humidity in the upper concrete floor construction, and ammonia in the floor. The newest hospital, built by an anthroposophic society, had low levels of dampness and few asthma symptoms (4%). Cat (*Fel d1*) and dog allergens (*Can f1*) were found in dust from all buildings (geometric mean 340 ng/g and 2490 ng/g, respectively). House dust mite allergens (*Der p1, Der f1,* or *Der m1*) were found in 75% of all samples (geometric mean 130 ng/g). There was no relationship between allergen levels and asthma symptoms.

CONCLUSIONS: Asthma symptoms may be related to increased humidity in concrete floor constructions and emission of 2-ethyl-1-hexanol, an indicator of dampness-related alkaline degradation of plasticiser DEHP. Moreover, geriatric hospitals can be contaminated by significant amounts of cat, dog and mite allergens.

KEY WORDS: asthma; building dampness; allergens; di(ethyl-hexyl)-phthalate (DEPH); dog allergen; 2-ethyl-1-hexanol; indoor air pollution

IN THE LAST DECADE, several studies have reported increases in respiratory symptoms among children or adults living in damp or mouldy dwellings.[1–3] There is considerably less information on the respiratory effects of dampness in the workplace. In a random sample of 532 occupationally active Swedes, we found an increased occurrence of airway symptoms among subjects working in a damp workplace buildings.[4] Moreover, two studies in daycare centres in Finland[5] and Taiwan[6] found a high prevalence of building dampness, and an increase in eye symptoms[5] and respiratory symptoms.[6] In another recent office study from Taiwan, an increased occurrence of respiratory symptoms was found in office buildings with signs of building dampness.[7] As exposure assessments in many dampness studies are exclusively based on self-reported signs of building dampness,[1,2] there is a clear need for studies where building dampness and exposure are assessed by technical and hygiene measurements.

Condensation dampness may occur due to a combination of poor ventilation and high indoor air humidity. Signs of such dampness may include visible mould growth on indoor surfaces, spots of dampness, or condensation on windows. A common problem in Scandinavia, however, is structural building dampness caused by water leakage, wetting of building material during the building process, or dampness in the floor construction due to capillary transportation of water from the soil to the concrete slab.[8] Structural building dampness may cause hidden microbial growth in the construction or chemical degradation of building material, sometimes with increased emission of specific volatile organic compounds (VOCs). One example is the degradation of di(ethyl-hexyl)-phthalate (DEPH), a common plasticiser in polyvinyl

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chloride (PVC) floor coatings or carpet glue, at increased humidity in concrete floor constructions. In such cases, emissions of ammonia and 2-ethyl-1-hexanol can be detected.[9]

In Sweden, geriatric health care is provided in small geriatric hospital units, and there are no in-patient beds for geriatric patients in the central hospitals. These geriatric hospitals have factors in common with both hospitals and home environments. In dwellings, common allergens in settled dust are a problem, both with respect to risk for sensitisation and exacerbation of symptoms in sensitised subjects.[10,11] Due to secondary contamination, common allergens may be found in public places, including day-care centers,[12] schools[13,14] and hospitals.[15–18] There is, however, little information on allergen contamination in geriatric hospitals and elderly care institutions.

The main aim of the investigation was to study the relationships between current asthma symptoms in hospital employees and the indoor environment, with special reference to dampness-related exposure and common allergens. The following hypotheses were tested: current asthma symptoms are related to different indicators of building dampness, building age, air exchange rate, formaldehyde, sum of VOCs, and concentrations of cat, dog, and mite allergens in settled dust. The protocol of the study was approved by the Ethics Committee of the Medical Faculty of Uppsala University. Results concerning symptoms and clinical signs from the eyes and the nasal mucosa have been published elsewhere.[19]

MATERIAL AND METHODS

Study population

The municipality of Ystad in southern Sweden has 25 000 inhabitants and eight geriatric hospitals. Four of these hospitals were selected as representing buildings of different age and design, irrespective of the occurrence of medical symptoms. The first was an old-fashioned hospital built in 1925; the second, built in 1985, had known dampness in the floor construction; the third was a modern building from 1993, constructed with conventional building techniques; and the last was built in 1995, with special design and building materials, avoiding plastic materials on interior surfaces. Although this building was designed and run by an anthroposophic society, its employees did not belong to the society, but were ordinary hospital workers recruited from the local labour market. All staff working day shifts ($n = 95$) were invited to participate in a medical investigation, including a doctor-administered standardised questionnaire. The investigation was conducted in January–February 1997, before the pollen season.

Information from the participants

The subjects were questioned by a doctor about allergies and other diseases, medications, occupational data, smoking habits and social status. Atopy was defined as a history of allergic manifestations related to exposure to common IgE-mediated allergens in Sweden (tree or grass pollen or furry animals), or a history of childhood eczema. In a subsequent investigation in Swedish painters, self-reported atopy was shown to be well in agreement with skin prick tests positive to common allergens (sensitivity 79%, specificity 75%).[20] Questions on asthma included one question on doctor's diagnosed asthma and year of diagnosis. In addition, three key questions on respiratory symptoms, obtained from the European Community Respiratory Health Survey (ECRHS), were used.[21] These three questions have been used in previous studies on the respiratory effects of building dampness in dwellings.[22,23] The recall period for airway symptoms was 12 months. Symptoms related to asthma were defined as having had, in the last 12 months: 1) wheezing or whistling in the chest; 2) at least one daytime attack of shortness of breath during exercise or while resting; or 3) at least one night-time awakening because of breathlessness or tightness in the chest. Having current asthma symptoms was defined as reporting at least one of the three asthma-related symptoms.

Information on exposures in the participant's own dwelling was obtained from an additional self-administered questionnaire, using the same questions as in earlier studies.[4,22,23] Information was requested on four different signs of building dampness over the last 12 months: 1) water damage or flooding; 2) dampness in the floor construction, indicated by blackness on parquet floor or bubbles under PVC floor coatings; 3) visible mould on indoor surfaces; 4) mouldy odour. The prevalence of subjects reporting at least one sign of building dampness in their dwelling was calculated. These questions were validated by comparing self-reported dampness with observations by an experienced occupational hygienist.[23]

Assessment of building dampness and exposure in the hospitals

The technical investigation comprised a building survey and technical measurements. Information was gathered on building age, types of building materials, types of ventilation systems, signs of building dampness, and smoking restrictions in the building. Measurements included dampness in the upper layer of the concrete floor, room temperature, relative air humidity, exhaust air flow, nitrogen dioxide (NO_2), ozone, formaldehyde, VOCs, and both viable and total concentrations of moulds and bacteria. Specific VOCs evaluated in this study included 2-ethyl-1-hexanol. Ozone and VOCs were also measured outside the buildings. Exposure measurements with direct reading instruments and pumped air sampling were taken on two different days in each building, with two 6-hour samples per building each day. Ozone and

NO_2 was measured by diffusion sampling over 1 week, with two samplers per building. All measurements were performed in January–February 1997, 1–2 weeks after the medical investigations had been completed.

The moisture content in the upper concrete floor surface was measured by a Waisala moisture instrument with probe HMP36 (Vaisala OY, Helsinki, Finland). The instrument was calibrated with a solution of potassium aluminium silicate ($KAlSiO_4$) and sodium chloride (NaCl). Dampness in the floor was also indicated by a direct reading dampness indicator. Measurements of room temperature and relative air humidity were performed by a thermohygrograph (Casella T 9420, Casella Ltd, London, UK) for 2 weeks in each building. The thermohygrograph was calibrated by comparison with a sling psychrometer. The exhaust air flow was measured in 15 hospital rooms in each building by thermoanemometer (ALNOR GGA 65P, Alnor OY, Turku, Finland), calibrated by the Swedish National Institute of Building Research prior to the measurements. The illumination was measured at ten sites in each building by a Hagner instrument (Hagner AB, Solna, Sweden).

Indoor NO_2 was sampled with a diffusion sampler (Toyo Roshi Kaisha Ltd, Tokyo, Japan), and analysed by a spectrophotometric method. An overall mass transfer coefficient of 0.10 cm/s was used in the calculations as suggested by Lee et al.[24] Ozone was measured with another diffusion sampler from the Swedish Environmental Research Institute (IVL), Gothenburg, Sweden.[25] Indoor concentrations of formaldehyde were sampled on passive samplers for 7 days, and analysed by high-performance liquid chromatography with glass fibre filters impregnated with 2,4-dinitrophenylhydrazine.[26] VOCs other than formaldehyde were sampled in charcoal sorbent tubes (Anasorb 747; SKC 226-81, SKC Inc, Eighty Four, PA, USA), at an air sampling rate of 0.2 L/min for 6 hours. The charcoal tubes were desorbed with 1 mL carbon disulphide, and analysed for specific VOCs, including 2-ethyl-1-hexanol, by means of a Hewlett Packard 5890 gas chromatograph with a mass selective detector (GC-MS) (HP 5970, Hewlett-Packard Co, Avondale, PA, USA).[27] The concentration of 2-ethyl-1-hexanol was determined by external standard technique, using a desorption efficiency of 76% reported for the actual desorption conditions.[27] Total VOC was determined on a gas chromatograph (HP 5880A) equipped with a packed non-polar column, and flame ionisation detector. The total concentration of VOC between the peaks of benzene (C6) and n-dodecane (C12) was calculated assuming the same response rate as for n-decane (decane-equivalents). In addition, the total concentration of VOC with a retention time below benzene (low boiling VOC) was determined, expressed as decane equivalents. The total concentration of volatile compounds (TVOC) was expressed as the mass summation of all detected compounds below n-dodecane.

Airborne micro-organisms were sampled on 25 mm nucleopore filters with a pore size of 0.4 m and a sampling rate of 1.5 L/min for 6 hours. The total concentration of airborne moulds and bacteria, respectively, was determined by the CAMNEA method.[28] Viable moulds and bacteria were determined by incubation on two different media. The detection limit for viable organisms was 50 colony forming units (cfu) per m^3 of air, and the detection limit for total moulds or bacteria was 5000 organisms per m^3 of air.

Common allergens in settled dust samples from the floor were collected in eight samples (two samples/hospital) by the following method: settled dust was collected by standardised vacuum cleaning of the floor in one ward (a patient's room), and one staff room for 10 minutes, using a 1000 W vacuum cleaner provided with a special dust collector containing a Millipore filter (pore size 6 μm, ALK Laboratories, Copenhagen, Denmark). After being passed through a sieve containing a filter with a porosity of 300 μm, the amount of fine dust was determined gravimetrically. Cat (*Fel d1*) and dog (*Can f1*) allergens were quantified with an enzyme-linked immunosorbent assay using monoclonal antibodies.[29] Major mite allergens in the dust were determined by enzyme immunoassays.[30] The detection limit was 10 ng/g of each mite allergen, and 20 ng/g for cat and dog allergens.

Statistical analysis

Analyses of relations between asthma symptoms and exposures were performed using crude and bivariate analysis and multiple logistic regression analysis. The χ^2 test or Fisher's exact test was used depending on the number in the cells, when analysing the relation between binary dependent and independent variables. Mann-Whitney U-test was used for the dichotomised variables. Multiple logistic regression analysis was applied using the SPIDA statistical package, version 6,[31] controlling for potential confounders such as age, sex, atopy, tobacco smoking and signs of building dampness in the participant's dwelling. For logistic regression, the programme uses a method described by Belsey[32] in which a condition index exceeding 20 was used as an indicator of collinearity problems. No collinearity problems were detected in the models. Both crude and adjusted odds ratios (OR), with a 95% confidence interval (CI), were calculated. For comparison, crude prevalence ORs (POR) were calculated. In all statistical analysis, two-tailed tests and a 5% level of significance were applied.

RESULTS

Personal factors

Of 95 daytime personnel, 88 participated in the questionnaire study (93%); one participant did not answer the questions on asthma symptoms and asthma. A total of 95% were females, 25% were current smokers, and 31% had a history of atopy (allergy to tree or grass pollen, furry animals, or a history of childhood eczema); 8% had doctor's diagnosed asthma and 7% had current asthma medication. For all of these subjects, asthma had occurred in childhood or early adolescence, prior to employment in their current workplaces; 17% reported at least one asthma symptom in the last 12 months (wheeze or attacks of breathlessness during daytime or at night). The most common respiratory symptom was wheeze (15%), and only 3% reported daytime attacks of shortness of breath. Among those with current asthma symptoms, 31% had ever had doctor's diagnosed asthma, and 31% had current asthma medication. Among those without any current asthma symptoms ($n = 72$), 3% had ever had doctor's diagnosed asthma, and 2% had regular asthma medication. Current tobacco smoking was more common among those with current asthma symptoms, as compared to those without such symptoms (47% vs. 21%, $P < 0.05$), but there was no significant difference with respect to atopy.

Building factors

All four hospitals were built of concrete or bricks, with slanting tile roofs, and all had windows that opened. The first building (A), a one-storey building, with a basement, was built in 1925, and had not been redecorated since 1955. The second building (B), built in 1985, had known dampness in the concrete floor construction. It was also a one-storey building with a basement under some of the area; the concrete slab of the rest was directly on the ground. The third building (C), a two-storey building with a basement, was built in 1993 using conventional building techniques. The last building (D) was built in 1995, using a special design. The foundation was a new type of concrete slab on the ground, electrically heated, and with thermal insulation placed under the slab. Building D had no plastic materials on the interior walls, floors or ceilings, and was painted inside with water-based beeswax glazing.

Building B was equipped with mechanical ventilation with both supply and exhaust air (mixed system) in the hospital rooms. The other three had only mechanical exhaust air ventilation in the hospital rooms.

Measured indoor climate and exposure measurements

Average room temperature was similar in all buildings, ranging from 22°–23°C. The average relative air humidity was 30–37%, and the air exchange rate was 0.50–0.91 turnover/hour. Increased dampness in the upper concrete floor surface (75–84%), and ammonia in the floor (3 ppm), was found in the two buildings with signs of building dampness in the floor construction (Table 1).

Indoor concentrations of NO_2, ozone and formaldehyde were low in all four buildings. The 7-day average indoor concentration of NO_2 was 8–11 g/m^3, and indoor concentrations of ozone ranged from 1.2–8.5 parts per billion (ppb). The average concentration of viable moulds and bacteria as well as total moulds and bacteria was low, and similar in all four buildings (Table 2). Among viable moulds and bacteria, low concentrations of *Penicillium* spp, *Dematiaceous hyphomycetes*, *Cladosporium* spp., *Streptomyces* spp., yeast, and *Aspergillus* spp. were detected in the air in the buildings. The compound 2-ethyl-1-hexanol, a well-known degradation product of DEHP, was detected only in the two buildings with signs of dampness in the floor construction. For other types of air pollutants, the indoor concentrations were similar in buildings with and without dampness in the floor construction (Table 2).

Cat allergen (*Fel d1*) and dog allergen (*Can f1*) were detected in all of the dust samples (Table 3). One hospital unit (building B) had one cat, and another (building D) had two cats and one dog. The two other units had no pets. The cats stayed permanently in the buildings, while the dog was there only in the daytime. The geometric mean concentration of *Fel d1* was 870 ng/g in the buildings with cats, and 180 ng/g in the buildings without cats. The geometric mean concentration of *Can f1* was 44 300 ng/g in the building with a dog present, and 1200 ng/g in the other buildings.

Table 1 Characteristics of the four hospital buildings

Factor	Hospital building			
	A	B	C	D
Building age	1925	1985	1993	1995
Average air exchange rate (turnover/hour)	0.51	0.81	0.91	0.50
Building dampness in the floor construction*	No	Yes	Yes	No
Type of floor coatings	PVC	PVC	PVC	Linoleum/clinker
Measured dampness in the floor (%)	58	84	75	69
Measured ammonia under the floor (ppm)	0	3	3	0.5

* Based on observation of signs from the floor material.
PVC = polyvinyl chloride; ppm = parts per million.

Table 2 Airborne indoor pollutants, mite allergens in dust, and air exchange rate in relation to building dampness

	Presence of signs of dampness			Absence of signs of dampness		
Environmental factor	*n*	T	Mean (min–max)	*n*	T	Mean (min–max)
Chemical indoor air pollutants						
Formaldehyde (μg/m³)	4	672	5 (2–8)	4	672	5 (3–9)
2-ethyl-1-hexanol (μg/m³)	8	48	12 (2–32)	8	48	<1 (<1–<1)
Sum of VOC	8	48	210 (19–984)	8	48	210 (46–570)
Micro-organisms in indoor air						
Viable bacteria (cfu/m³)	8	48	70 (<50–100)	8	48	60 (<50–100)
Total bacteria (*n*/m³)	8	48	8400 (<5000–19 000)	8	48	8500 (<5000–19 000)
Viable moulds (cfu/m³)	8	48	130 (<50–190)	8	48	100 (<50–190)
Total moulds (*n*/m³)	8	48	6000 (<5000–9700)	8	48	6100 (<500–9900)
Mite allergens in dust.						
Sum of *Der p1, Der f1*, and *Der m1* (ng/g dust)	4	NA	360 (<60–1280)	4	NA	710 (<60–2020)
Ventilation parameters.						
Carbon dioxide (ppm)*	4	672	650 (590–770)	4	672	850 (710–1200)
Mean air exchange rate (turnovers/hour)*	30	NA	0.86 (0.81–0.91)	30	NA	0.51 (0.50–0.51)

* Based on air flow measurements in 15 rooms per hospital (min–max refers to mean values per building).
n = number of samples; T = total sampling time for air samples (hours); VOC = volatile organic compounds; cfu = colony forming units; NA = not applicable; ppm = parts per million.

Mite allergens were detected in 75% of the samples (Table 3). The most prevalent mite allergen was *Der f1*, while *Der p1* and *Der m1* were detected in only 38% of the samples. There were no significant differences between buildings with and without signs of building dampness with respect to the total amount of settled dust or concentration of mite allergens (the sum of *Der p1, Der f1* and *Der m1*). The total amount of collected fine fraction dust per sample ranged from 65 mg to 450 mg (mean 203 mg).

Current asthma symptoms in relation to building dampness

In total, 50 of the 87 participants worked in the two hospitals with signs of dampness in the floor construction, and nine of the 87 reported at least one sign of building dampness in their own dwelling. In the initial crude bivariate analysis, there was a significant increase in asthma symptoms in the two damp hospitals, with 2-ethyl-1-hexanol in indoor air (crude OR 6.2, crude POR 4.8). This relationship was significant even when adjusting for personal factors and signs of dampness in the participant's dwelling by multiple logistic regression analysis (Table 4). In addition, there were significant relationships between asthma symptoms and two objective signs of dampness in the floor construction (relative humidity in the upper floor construction, and ammonia under the floor carpet) (Table 5). No relationship was observed between asthma symptoms and building age, air exchange rate, air humidity, indoor formaldehyde or sum VOC, or concentration of cat, dog or mite allergens in floor dust. There were no significant increases in current use of asthma medications in the two damp buildings.

Table 3 Concentration of common allergens in settled floor dust samples (n = 8) collected in four geriatric hospitals

	Concentration of allergen (ng/g)	
Type of allergen	M (min–max)	GM (GSD)
House dust mites		
Der p1	26 (<20–59)	22 (3.1)
Der f1	340 (<20–1875)	62 (5.4)
Der m1	170 (<20–1150)	46 (11.5)
Furry animals		
Cat allergen (*Fel d1*)	1 520 (96–10 150)	340 (3.6)
Dog allergen (*Can f1*)	18 200 (997–123 000)	2 490 (4.9)

M = arithmetic mean; GM = geometric mean; GSD = geometric standard deviation.

Current asthma symptoms in the new building with special design

A total of 23 subjects worked in the newest building designed and run by an anthroposophic society. They had a similar prevalence of atopy (30% vs. 31%) and doctor diagnosed asthma (8.7% vs. 7.9%), and similar age and smoking habits to the staff in the other three hospitals. However, they had numerically less asthma medication (5.3% vs. 7.9%) and fewer current asthma symptoms (4% vs. 22%). The difference in asthma symptoms was statistically significant ($P = 0.03$) when adjusting for potential confounders (age, sex, atopy, smoking, and dampness in the participant's dwelling) by multiple logistic regression. Despite being the newest hospital, this building had low relative humidity in the floor surface (69%), and the lowest indoor concentrations of viable mould spores and VOCs.

DISCUSSION

In this study we were able to demonstrate a relationship between asthma symptoms in adults, and dampness-related alkaline degradation of DEPH in PVC building

Table 4 Prevalence of current asthma symptoms* in relation to building dampness, in geriatric hospital buildings as well as in the dwellings of hospital workers

Site of building dampness	Current asthma symptoms in buildings: Without dampness (%)	With dampness (%)	Crude OR (95%CI)	Adjusted OR (95%CI)†
Geriatric hospital buildings	5.4	26.0	6.2 (1.5–25.5)‡	8.6 (1.3–56.4)‡
Dwelling of hospital personnel	15.4	33.3	2.8 (0.63–12.1)	5.7 (0.72–45.4)

*Subjects reporting whistling in the chest, daytime attacks of shortness of breath during exercise or rest, or waking because of breathlessness or tightness in the chest.
† Multiple logistic regression model with determinants: age, sex, atopy, current smoking, building dampness in the participant's dwelling, and building dampness in the geriatric hospital building.
‡ $P < 0.05$.
OR = odds ratio; CI = confidence interval.

material, indicated by presence of 2-ethyl-1-hexanol in indoor air. The study was small and the number of buildings limited, but to our knowledge it is the first study on this topic in workplace buildings, and one of the few on problems of dampness in hospitals.

The design was cross-sectional; in such studies selection effects may cause both underestimation and overestimation of the true relationship. Selection bias due to low response rate is less likely, as the participation rate was high (93%). A time difference between clinical investigations and exposure measurements may induce a possible bias. In this study, however, hygiene measurements and building inspections were made 1–2 weeks after the medical investigations. Moreover, similar results were obtained both in the crude analysis and by logistic regression analysis, and by different measures of dampness in the concrete flooring. Thus, we do not believe that our conclusions are seriously biased by selection or response errors, or due to chance findings.

There is little information in the literature on building dampness in workplace buildings, particularly on dampness in concrete floor construction, with chemical degradation of plasticisers. Here, 50% of the buildings had this type of building dampness. A similar prevalence of dampness in floor construction (38%) was found in a previous study of geriatric hospitals within a defined geographical area.[33] Other studies in workplace buildings have dealt mainly with water-leakage causing microbial growth in organic building materials. In a random sample of 30 day-care centres in Espoo, Finland, water damage, mainly from roof leaks, had occurred in 70% of the centres.[5] In another study from a random sample of 56 day-care centres in Taipei, Taiwan, building dampness was found in 75.3% of the centres, visible mould in 25.8%, water damage in 49.3%, and flooding in 57.2%.[6] In a random sample of occupationally active adults from the total Swedish population (aged 20–65 years), the 12-month prevalence of dampness in workplace buildings was lower (13%), and there were visible signs of dampness in the floor construction, indicated

Table 5 Selected building characteristics and measurement among subjects with and without asthma symptoms

	Asthma symptoms* (n = 15) M (SD)	No asthma symptoms (n = 72) M (SD)
Building-related measurements		
Building age (years)	14 (17)	18 (26)
Ventilation flow (m^3/hour)	57 (13)	49 (18)
Relative humidity in the floor (%)	79 (7.6)	73 (9.1)†
Ammonia under the floor (ppm)	2.6 (1.0)	1.7 (1.4)†
Airborne measurements		
Relative air humidity (%)	33 (2)	32 (2)
Indoor formaldehyde ($\mu g/m^3$)	3 (2)	5 (2)
Indoor sum of VOCs ($\mu g/m^3$)	240 (59)	220 (74)
Settled dust allergens		
Mite allergens (ng/g)‡	550 (350)	480 (480)
Cat allergen *Fel d1* (ng/g)	660 (1 280)	1 810 (2 320)
Dog allergen *Can f1* (ng/g)	5 700 (17 600)	22 000 (31 600)

* Subjects reporting whistling in the chest, daytime attacks of shortness of breath during exercise or rest, or wakening because of breathlessness or tightness in the chest.
† $P < 0.01$ by Mann-Whitney U-test.
‡ Sum of *Der p1, Der f1*, and *Der m1*.
ppm = parts per million; VOC = volatile organic compound.

by blackening of parquet floor or bubbles under PVC flooring, in 6% of all workplace buildings.[4]

We found a relationship between measured signs of building dampness and current asthma symptoms (adj OR = 8.6, 95%CI 1.3–56.4). There were indications of dampness-related degradation of DEHP in PVC floor materials, with emission of 2-ethyl-1-hexanol, but no indications of microbial growth. A non-significant increase in wheezing (adj OR = 1.28, 95%CI 0.44–3.73) in damp and mouldy day-care centres was found in the Finnish day-care centre study,[5] and a significant increase in wheeze in the Taiwanese study (adj OR = 2.87, 95%CI 1.19–6.94).[6] To our knowledge, there are few other studies on asthma symptoms in damp workplace buildings.[7] In a subsequent study in dwellings, signs of building dampness in the floor construction were associated with an increase in current asthma (adj OR = 4.6, 95%CI 2.0–10.5).[23]

Building technology has changed in recent decades, and new materials have been introduced. PVC is frequently used in consumer products, floor glues and indoor surface materials. Plasticiser DEHP, also called dioctyl-phthlate, is widely used in PVC plastics and may constitute 40% of the PVC material.[34] There is some evidence from previous studies suggesting that emissions related to this type of plasticiser could have respiratory effects. Preterm infants exposed to DEHP from respiratory tubings have been reported to have a higher risk for impaired pulmonary function.[35] In addition, a case of occupational asthma was recently reported in a factory producing PVC bottle caps, suggesting di-octyl-phthalate as causative agent.[36] At alkaline hydrolysis of DEHP, 2-ethyl-1-hexanol and mono (2-ethylhexyl)phthalate (MEHP) is formed. As 2-ethyl-1-hexanol is a volatile compound, it can easily be detected by conventional VOC measurements. Presence of 2-ethyl-1-hexanol is commonly used in Sweden as an indicator of alkaline degradation of DEPH.[9] In an office building in the USA, degradation of plasticiser with emission of higher alcohols, including 2-ethyl-1-hexanol, was identified as a possible cause of indoor problems.[37] The compound MEHP is a larger and less volatile compound, and has been reported to induce bronchial hyperresponsiveness in rats.[38] It has been hypothesised that MEHP mimics prostaglandins and thromboxanes in the lungs and thereby increases the risk of inducing airway inflammation.[39] Recently, a matched case-control study in a cohort of 3754 new-borns in Oslo, Norway, demonstrated an increased risk for bronchial obstruction in the presence of PVC floor materials in dwellings (OR = 1.89, 95%CI 1.14–3.14).[34] Moreover, a relationship between the presence of plastic wall materials in the home and lower respiratory tract symptoms in children has been reported.[40] A special problem in Sweden has been a particular brand of casein-containing mortar used in 1977–1983,[41] but none of the buildings in the present study contained this kind of mortar. The concrete structure was normal concrete mix and not self-desiccation concrete, a new type of concrete used to reduce dampness in construction.[42]

The employees in hospital D, built by an anthroposophic society, had fewer current asthma symptoms. This could not be explained by differences in age, sex, atopy, smoking or doctor diagnosed asthma. Moreover, the employees were not anthroposophs themselves, but were recruited from the common local labour market. There were no plastic materials on interior surfaces, and low relative humidity under the flooring made of linoleum or clinker. A new type of concrete slab had been used, electrically heated and with thermal insulation placed under the concrete slab. Such constructions could be expected to have low relative humidity in the concrete floor construction, due to a favourable thermal profile. It has previously been reported that children attending anthroposophic schools have a lower prevalence of asthma and atopic disease than other children—the authors interpreted this as being associated with an anthroposophic lifestyle.[43] Our results suggest that certain aspects of the indoor environment in these buildings may also be beneficial to respiratory health.

The analysis of common allergens in settled dust indicated the presence of cat and dog allergens in all samples, and mite allergens in 75% of the samples. The source of the allergens in our study could partly be due to the presence of cats or dogs in two of the hospital units. Even in the other hospitals without any pets, relatively high levels of cat and dog allergens were found, suggesting secondary contamination. There are few previous measurements of these allergens in hospitals. In a British study, the highest allergen concentration was found in upholstered chairs in hospitals, with geometric mean concentrations of 22.9 ng/g *Fel d1* and 21.6 ng/g *Can f1*.[16] Mite allergens were detected in most samples (75%) in our study, which was performed in winter, but the levels were mostly relatively low. One sample (13%) was above the proposed level for sensitisation, at 2000 ng/g mite allergens.[44] In the British hospital study, the geometric mean concentration of *Der p1* was about 100 ng/g in carpet dust.[16] In a Danish hospital, only one of 60 dust samples (2%) had total mite-allergen levels above 2000 ng/g in settled dust.[17] In one study in a tertiary care hospital in Delaware, USA, no *D. farinae* or *D. pteronyssinus* was found in 60 hospital dust samples during the winter season, and the mite density was low even during summertime.[15] Finally, measurements in a Singapore hospital showed lower mite allergen than in homes. Mite allergens were detected in 57% of all dust samples, but only one sample out of 74 (1%) had *Der p1* concentrations above the 2000 ng/g level.[18] As different assays and different sampling protocols can be used in different studies, a direct comparison of allergen levels reported from different hospital studies is not possible.

In conclusion, asthma symptoms may be related to increased humidity in concrete floor constructions and emission of 2-ethyl-2-hexanol, an indicator of dampness-related alkaline degradation of plasticiser DEHP used in PVC materials. This indicates that building dampness in the concrete floor construction can be a risk factor for respiratory health, in combination with PVC materials. A preventive measure could be to consider the use of the latest building technology in new buildings, creating low levels of relative humidity in the concrete flooring. Moreover, the study shows that geriatric hospitals can be contaminated by significant amounts of cat and dog allergens in settled floor dust, and to some extent also mite allergens.

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RÉSUMÉ

CADRE : Symptômes asthmatiques chez des adultes en relation avec l'environnement des intérieurs.

OBJECTIF : Etudier les relations entre les symptômes asthmatiques actuels (sifflement ou crises d'oppression) et l'environnement des intérieurs ainsi que l'humidité dans les hôpitaux.

SCHÉMA : Une étude parmi le personnel de quatre hôpitaux gériatriques (n = 87) au cours de l'hiver. Ont été mesurés les polluants internes, l'humidité dans les sols en béton et les allergènes dans la poussière de dépôt. Une analyse à régression multiple a été appliquée avec ajustement pour l'âge, le sexe, l'atopie et l'humidité dans la résidence.

RÉSULTATS : Des symptômes asthmatiques actuels ont été signalés chez 17% des sujets et le diagnostic d'asthme avait été posé par le médecin chez 8%. Les symptômes asthmatiques étaient plus fréquents (OR aj. = 8,6 ; IC95% 1,3–56,7) dans deux bâtiments portant des signes de dégradation et du di(ethyl-hexyl)-phthalate (DEHP) liés à l'humidité dans les matériaux de recouvrement du sol en chlorure de poly-vinyl (PVC). Cette dégradation a été détectée par la présence de 2-etyl-1-hexanol (2–32 μg/m^3) dans l'air des intérieurs (CAS nr 104-76-7). Les symptômes asthmatiques sont en relation avec une humidité relative plus élevée dans la couche supérieure des sols en béton et avec la présence d'ammoniaque dans le plancher. Dans l'hôpital le plus récent, construit par une société anthroposophique, les niveaux d'humidité étaient faibles et les symptômes asthmatiques rares (4%). On a trouvé des allergènes de chat (*Fel d1*) et de chien (*Can f1*) dans la poussière de tous les bâtiments (moyenne géométrique respectivement de 340 ng/g et 2.490 ng/g). Des allergènes de la mite de la poussière de maison (*Der p1, Der f1*, ou *Der m1*) ont été décelés dans 75% de tous les échantillons (moyenne géométrique 130 ng/g). On n'a pas relevé de relation entre les niveaux d'allergènes et les symptômes asthmatiques.

CONCLUSION : Les symptômes asthmatiques peuvent être en rapport avec une augmentation d'humidité dans les constructions avec sol en béton et avec l'émission de 2-etyl-1-hexanol, un indicateur d'une dégradation alcaline du plastic DEHP, liée à l'humidité. De plus, les hôpitaux gériatriques peuvent être contaminés par des quantités significatives d'allergènes de chat, de chien et de mite.

RESUMEN

MARCO DE REFERENCIA : Síntomas de asma en adultos en relación con el ambiente interior.

OBJETIVOS : Estudiar la relación entre los síntomas asmáticos (ataques de disnea), el ambiente interior y la humedad en los hospitales.

MÉTODO : Un estudio del personal (n = 87) en invierno en cuatro hospitales geriátricos. Se midieron los contaminantes del aire interior, la humedad en el piso de concreto y los alergenos en el polvo. Se aplicó el análisis de regresión logística múltiple, ajustado a edad, sexo, atopía y humedad en la casa.

RESULTADOS : Se hallaron síntomas asmáticos actuales en el 17% y el 8% tenía diagnóstico médico de asma. Los síntomas asmáticos eran más frecuentes (adj OR = 8,6 ; IC95% 1,3–56,7) en dos edificios con alteraciones relacionadas con la degradación del di(ethyl-hexyl)-phthalato (DEHP) asociada a la humedad, en pisos de cloruro de polivinilo (PVC). Esta degradación fue detectada por la presencia de 2-etil-1-hexanol (2–32 μg/m^3) en el aire interior (CAS nr 104-76-7). Los síntomas asmáticos estaban relacionados con una mayor humedad relativa en la capa superior de la construcción de cemento del piso y a la presencia de amoníaco en el piso. El nuevo hospital, construido por una sociedad antroposófica, tenía niveles más bajos de humedad y escasos síntomas de asma (4%). Alergenos de gatos (*Fel d1*) y de perros (*Can f1*) se hallaron en el polvo de todos los edificios (media geométrica 340 ng/g y 2490 ng/g, respectivamente). Alergenos de ácaros en el polvo de la habitación (*Der p1, Der f1*, o *Der m1*) fueron hallados en el 75% de todas las muestras (media geométrica 130 ng/g). No existía relación entre los niveles de alergenos y los síntomas del asma.

CONCLUSIONES: Los síntomas de asma pueden estar relacionados con una humedad aumentada en las construcciones con pisos de concreto y emisión de 2-etil-1-hexanol, un indicador de degradación alcalina asociada a la humedad del material plástico DEHP. Además, los hospitales geriátricos pueden estar contaminados por cantidades significativas de alergenos de gatos, perros y ácaros.