

Association between ventilation rates in 390 Swedish homes and allergic symptoms in children

Abstract The aim of the study was to test the hypothesis that a low-ventilation rate in homes is associated with an increased prevalence of asthma and allergic symptoms among children. A total of 198 cases (with at least two of three symptoms: wheezing, rhinitis, eczema) and 202 healthy controls, living in 390 homes, were examined by physicians. Ventilation rates were measured by a passive tracer gas method, and inspections were carried out in the homes. About 60% of the multi-family houses and about 80% of the single-family houses did not fulfill the minimum requirement regarding ventilation rate in the Swedish building code (0.5 air changes per hour, ach). Cases had significantly lower ventilation rates than controls and a dose–response relationship was indicated.

**C. G. Bornehag^{1,2,3}, J. Sundell²,
L. Hägerhed-Engman¹,
T. Sigsgaard⁴**

¹Swedish National Testing and Research Institute, Borås, Sweden, ²Technical University of Denmark, Lyngby, Denmark, ³Public Health Sciences, Karlstad University, Sweden, ⁴Aarhus University, Aarhus, Denmark

Key words: Ventilation rate; Homes; Asthma; Allergic symptoms; Children.

C. G. Bornehag
Public Health Science, Karlstad University, SE-651 88
Karlstad, Sweden
Tel.: +46-54-7002540
Fax: +46-54-7002523
e-mail: carl-gustaf.bornehag@kau.se

Received for review 25 February 2004. Accepted for publication 28 March 2005.
© Indoor Air (2005)

Practical Implications

A low-ventilation rate of homes may be a risk factor for allergies among children. Families with allergic children should be given the advice to have good ventilation in the home. In investigations, of associations between environmental factors and allergies, the air change rate in homes has to be considered.

Background

Increased costs for energy, and thus for heating of buildings, starting with the oil embargo in 1973, has induced tightening of building envelopes and reduced ventilation in cold climate (Öie et al., 1999; Sundell, 1994). This decrease in ventilation rates coincides in time with the increase in allergic diseases among children and adults.

In a multidisciplinary review of the scientific literature on ventilation and health (EUROVEN) it was concluded that a low-ventilation rate in offices is associated with an increased risk of health effects (SBS symptoms) (Seppänen and Fisk, 2002; Wargocki et al., 2002). However, only a few conclusive studies were found regarding ventilation of homes and its association to health effects. For homes in a Nordic

climate it was concluded that ventilation rates above 0.5 air changes per hour (ach) decrease the risk of infestation of house dust mites, and thus the risk of allergic sensitization and symptoms. In one study from Norway (Öie et al., 1999) and one from Sweden (Emenius et al., 2004) no obvious direct association could be seen between ventilation rates of homes and asthma and allergy among children. However, in the study by Öie et al. it was found that bronchial obstruction among children was associated with some pollution sources (vinyl surfaces on walls and floors, and 'dampness') and that this association became elevated at a low-ventilation rate (below 0.5 ach).

The aim of this study was to test the hypothesis that a low-ventilation rate in homes is associated with asthma and allergic symptoms among children in Sweden.

Method

This study is a part of a large investigation on the impact of the indoor environment on asthma and allergy among children in Sweden, DAMPNES IN BUILDINGS AND HEALTH (DBH) (Bornehag et al., 2004a). The first step of the DBH-study was a cross-sectional questionnaire investigation involving 14,077 children aged 1–6 years in Värmland, Sweden (DBH-step 1) (Bornehag et al., 2004b). The present study is a part of the second step (DBH-step 2): a nested case–control investigation including 198 symptomatic children (cases) and 202 non-symptomatic controls. A description of the design of the questionnaire study (DBH-step 1) and the selection procedure for cases and controls (DBH-step 2) are described in Bornehag et al. (2004a).

Inclusion criteria for cases and controls

The selection criteria for the cases in DBH-step 2 were (1) in the initial 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, 1.5 years later, they had to: (2) report at least two of three possible symptoms. Inclusion criteria for the controls (i.e. non-cases) were (1) no symptoms in the first questionnaire and (2) no symptoms in the follow-up questionnaire. For both groups they should not have: (3) rebuilt their homes because of moisture problems, and (4) 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 cooperate 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 is described elsewhere (Bornehag et al., unpublished).

Building investigations

The 400 children lived in 390 buildings, there being 10 pairs of siblings. Between October 2001 and April 2002, visual inspections and indoor air quality (IAQ) assessments were performed in the 390 dwellings. Six professional inspectors according to a manual carried out the inspections.

Ventilation rates of the entire home and of the bedroom of the index-child were measured during 1 week with a passive tracer gas method – ‘the homogeneous emission technique.’ This PFT (perfluorocarbon tracer) technique, described in NT VVS 118

(Nordtest, 1997), yields information on the mean ventilation rates during the measured week.

Physical examination

The medical examinations of the 400 children (3–8 years) were performed during the same 2 weeks as the technical inspections and measurements. A team of four medical doctors examined the children following a structured anamnesis. A blood sample was drawn from 387 children and screened for common allergens (Phadiatop®). The allergens screened for were: timothy, common silverbirch, mugwort, cat, horse, and dog, two house dust mites (*Dermatophagoides pteronyssinus* and *Dermatophagoides farinae*), and one mould (*Cladosporium*).

Statistical analysis

Differences in ventilation rates between buildings were tested with parametric and non-parametric tests (Student’s *t*-test and Mann–Whitney *U*) as the measured ventilation rates were not fully normally distributed. In order to investigate dose–response relationships, the ventilation rate data were divided into quartiles. Associations were then estimated with crude and adjusted Odds Ratio (OR) in logistic regression models. Adjustments were made for sex, smoking in the family, and inspector’s observations of moisture-related problems in the home expressed in a 5-step scale from ‘no’ to ‘severe damages.’ Finally, we have earlier reported an association between the concentration of phthalates in dust (butyl benzyl phthalate, BBzP) and case status (Bornehag et al., 2004c). Therefore, adjustments were made for BBzP in dust in quartiles. Trends in data were tested with linear-by-linear associations. A *P* value of less than 0.05 was used as significance value. Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, 11.5).

The local Ethics Committee approved the study.

Results

The physical examination of the children showed good agreement between doctors’ diagnoses and case–control status. All children with obvious asthma were found among cases while two children with rhinitis and eight children with eczema were found among controls. Approximately half of the cases with doctor-diagnosed asthma and eczema, respectively, were IgE positive to at least one of the tested allergens. Among cases with asthma, 49 children were non-atopics (IgE-negative) and 54 were atopics (IgE-positive) and among cases with eczema, 54 children were non-atopics and 56 were atopics. Regarding rhinitis, about 80% of the cases were IgE-positive, i.e. 16 children were non-atopics and 68 were atopics.

Type and age of homes

Almost 83% of the children lived in single-family houses (Table 1). Half of the single-family houses were constructed 1960 or earlier; row houses and multi-family houses were somewhat newer. Most single-family houses had natural ventilation and a kitchen fan, and multi-family houses were mostly ventilated with mechanical systems.

Building characteristics and ventilation rates

Valid ventilation rates in the 390 available buildings were obtained for 386 homes as regards mean ventilation for the total building, and for 378 homes regarding the index-child's bedroom.

Multi-family houses had higher mean ventilation rates than other types of homes (Table 1). In the following, results are mainly focused on single-family houses as they represent 83% of the study population and consist of more homogenous groups of buildings and families (Bornehag et al., 2004b).

Single-family houses with a mechanical exhaust and supply ventilation system had higher ventilation rates compared with buildings with other ventilation systems (Table 2). Buildings from the 1960s and the 1970s (1961–1983) had lower ventilation rates than buildings from earlier or later construction periods, and homes with concrete on ground as foundation were found to have the lowest ventilation rate. Finally, single-family houses with only one floor had lower ventilation rates compared to buildings with more than one floor.

Ventilation rate and health

There were no significant differences in type of buildings between cases and controls. Regarding single-family

houses, cases were more likely than controls to live in houses that had mechanical exhaust ventilation, were constructed in the period 1961–1983, had a concrete foundation, and were one-storey buildings (Table 2).

Cases living in single-family houses had significantly lower ventilation rates than controls, both in the total building and in the child's bedroom (Table 3). In multi-family houses and row houses there were no significant differences in ventilation rates between cases and controls.

In single-family houses, a dose–response relationship between ventilation rate and the risk of being a 'case-child' was found in crude analyses with data on ventilation rates divided into quartiles (Table 4). When adjusting for potential confounders the same tendency of a dose–response relationship as in the crude analyses was found, but the results did not reach significance.

Doctor-diagnosed disease

Case children with doctor-diagnosed rhinitis and eczema, living in single-family houses had a lower ventilation rate in the child's bedroom compared with controls (Table 5). However, no association was found between ventilation rate and doctor-diagnosed asthma. When the ventilation rates were divided into quartiles, trend analysis (linear-by-linear association) showed a significant association ($P < 0.05$) for rhinitis (data not shown). When comparing the group with the lowest ventilation rates (first quartile) with the group with the highest ventilation rates (fourth quartile) there was an increased risk of rhinitis among children in the first quartile, although, not significant (OR 1.65; 95% confidence interval (CI) 0.81–3.35).

Table 1 Description of the homes for 198 cases and 202 controls

Building characteristics ^a	Number of buildings with different characteristics [n (%)]			
	Single-family houses (SH)	Row houses (RH)	Multi-family houses (MH)	Total
Number of buildings in the study: n (%)	323 (82.8)	23 (5.9)	44 (11.3)	390 ^b
Construction period				
Till 1960	159 (49.2)	3 (13.0)	17 (38.6)	179 (45.9)
1961–1983	128 (39.6)	12 (52.2)	17 (38.6)	157 (40.3)
1984 onwards	36 (11.2)	8 (34.8)	10 (22.7)	54 (13.9)
Ventilation system				
Natural incl. kitchen fan	239 (74.0)	8 (34.8)	10 (22.8)	257 (65.9)
Mechanical exhaust	52 (16.1)	11 (47.8)	30 (68.2)	93 (23.8)
Mechanical exhaust and supply	32 (9.9)	4 (17.3)	4 (9.1)	40 (10.2)
Mean ventilation rate ^c				
Ach in total building (n)	0.36 (320)	0.35 (23) ^{RH–MH*}	0.48 (43) ^{SH–MH***}	
Ach in child's bedroom (n)	0.35 (315)	0.37 (23) ^{RH–MH*}	0.51 (40) ^{SH–MH***}	

* $P < 0.05$; *** $P < 0.001$.

^aAll data from inspections in DBH-step 2.

^bThere were 10 pairs of siblings in the study population.

^cTest of difference between groups of buildings made by Student's *t*-test.

Table 2 Difference in mean ventilation rate between different building characteristics in single-family houses

Building characteristics	Ventilation rate ^a (mean ach)		Case-Control status [n (%)]	
	Total building	Child's bedroom	Cases (n = 161)	Controls (n = 172)
Ventilation system				
Natural (N)	0.37	0.34 ^{N-MES**}	114 (71.7)	128 (78.0)
Mechanical exhaust (ME)	0.32 ^{ME-MES***}	0.32 ^{ME-MES**}	31 (19.5)	20 (12.2)
Mechanical exhaust/supply (MES) ^b	0.44	0.47	14 (8.8)	16 (9.8)
Construction period				
Till 1960 (I)	0.41 ^{I-II***}	0.37 ^{I-II***}	73 (45.3)	93 (54.1)
1961-1983 (II)	0.30 ^{II-III**}	0.29 ^{II-III***}	77 (47.8)	54 (31.4)
1984 onwards (III)	0.39	0.42	11 (6.8)	25 (14.5)
Type of foundation				
Basement (B)	0.36 ^{B-CS*}	0.34 ^{B-CS*}	60 (38.0)	67 (39.4)
Crawl Space (CS)	0.42 ^{CS-C***}	0.40 ^{CS-C**}	40 (25.3)	55 (32.4)
Concrete on ground (C)	0.32	0.31	58 (36.7)	48 (28.2)
Number of floors				
1 floor	0.31***	0.29***	56 (35.2)	53 (31.4)
>1 floor	0.39	0.38	103 (64.8)	116 (68.6)

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

^aTest of difference in mean air change rate (ach) between groups made by Student's *t*-test.

^bMechanical exhaust and supply system.

Table 3 Differences in mean ventilation rate between cases and controls in different groups of buildings

Type of buildings	Cases	Controls	<i>P</i> -value	
			<i>t</i> -test	Mann-Whitney <i>U</i>
Single-family houses (n)	161	172		
Mean ach in total building (n)	0.34 (161)	0.38 (169)	0.025	0.014
Ach in child's bedroom (n)	0.32 (158)	0.37 (166)	0.020	0.011
Chain houses (n)	12	11		
Mean ach in total building (n)	0.37	0.32	0.627	0.622
Ach in child's bedroom (n)	0.40	0.33	0.412	0.712
Multi-family houses (n)	25	19		
Mean ach in total building (n)	0.49 (25)	0.47 (18)	0.793	1.000
Ach in child's bedroom (n)	0.50 (23)	0.52 (17)	0.807	0.967
All types of building (n)	198	202		
Mean ach in total building (n)	0.36 (198)	0.39 (198)	0.126	0.053
Ach in child's bedroom (n)	0.34 (193)	0.38 (194)	0.099	0.068

Specific IgE in blood

Table 6 examines the ventilation rate among cases and controls with and without specific IgE in blood (i.e.

atopics and non-atopics). Within the group of cases and controls there were no difference in ventilation rate between atopics and non-atopics.

Discussion

Ventilation rate

The measured air change rate in the 390 buildings was generally low. The minimum requirement for homes according to the Swedish building code is 0.5 ach. The mean ventilation rate for single-family houses was 0.36 ach and for multi-family houses 0.48 ach. About 80% of the single-family houses and 60% of the multi-family houses did not fulfill the minimum legal requirements. In an earlier nationwide investigation it was found that about 86% of the single-family houses and about 50% of the multi-family houses did not fulfill the minimum requirements (Stymne et al., 1994; Norlén and Andersson, 1995). Furthermore, it was shown in the present study that buildings from the

Table 4 Association between ventilation rate (ach) indoor and case status in single-family houses

Quartile for ventilation rate	Odds ratio (95% CI)					
	Total building			Child's bedroom		
	Min-Max (ach)	Crude analysis	Adjusted analysis ^a	Min-Max (ach)	Crude analysis	Adjusted analysis ^a
Fourth quartile (ref)	0.44-1.43	1.0	1.0	0.42-1.79	1.0	1.0
Third quartile	0.33-0.43	1.32 (0.71-2.44)	1.17 (0.57-2.42)	0.31-0.41	0.90 (0.48-1.69)	0.94 (0.46-1.95)
Second quartile	0.24-0.33	1.52 (0.82-2.82)	1.35 (0.66-2.74)	0.21-0.31	1.56 (0.84-2.90)	1.56 (0.77-3.12)
First quartile	0.05-0.24	1.99 (1.07-3.71)	1.95 (0.94-4.04)	0.02-0.21	1.73 (0.93-3.22)	1.77 (0.87-3.65)
<i>P</i> -value ^b		0.027	—		0.029	—

Association expressed as crude and adjusted odds ratio (OR) with 95% confidence interval (CI).

^aAdjusted for sex, smoking in family, observed moisture problems in the dwelling [classified from 1 (extensive problems) to 5 (no observed moisture problems)] and butyl benzyl phthalate (BBzP) in dust (quartiles).

^bLinear-by-linear association.

Table 5 Ventilation rate in single-family houses for case children with a doctor-diagnosed disease compared with controls

Diagnosed disease ^a	Cases with disease		Controls		P-value	
	n	Mean ventilation (ach)	n	Mean ventilation (ach)	t-test	Mann-Whitney U
Total building ventilation						
Asthma	101	0.36	169	0.38	0.253	0.148
Rhinitis	82	0.35	169	0.38	0.233	0.086
Eczema	107	0.34	169	0.38	0.032	0.028
Children's bedroom ventilation						
Asthma	99	0.34	166	0.37	0.207	0.195
Rhinitis	79	0.32	166	0.37	0.073	0.023
Eczema	106	0.31	166	0.37	0.024	0.016

^aObvious doctor-diagnosed disease (asthma, rhinitis, or eczema, respectively) among cases (possible disease and no disease excluded) compared with all controls.

Table 6 Difference in ventilation rate for controls and cases with and without IgE in blood (atopics and non-atopics) in single-family houses

Ventilation	Mean and (median) ventilation rate, (ach)			
	Controls		Cases	
	Non-atopic (142)	Atopic (21)	Non-atopic (79)	Atopic (77)
Total building	0.38 (0.35)	0.38 (0.35)	0.33 (0.32)	0.34 (0.30)
Children's bedroom	0.37 (0.32)	0.36 (0.33)	0.32 (0.29)	0.31 (0.27)

sixties and seventies had the lowest ventilation rate. This finding accords well with reports from Norway (Öie et al., 1998, 1999).

In two recent Nordic studies, no direct association was found between home ventilation rates and asthma and allergy among children (Emenius et al., 2004; Öie et al., 1999). However, in both studies much higher ventilation rates were reported and the frequency of multi-family houses was higher than in the current study. In the Norwegian study, 63% of the homes had a ventilation rate above 0.5 ach and 52% of the buildings were multi-family houses (Öie et al., 1998, 1999). In the Swedish study, the mean ventilation rate was 0.68 ach and about 75% of the buildings were multi-family houses (Emenius et al., 2004). The tracer gas method used and the laboratory performing the analyses was the same in all these studies. The higher ventilation rates in the studies by Öie et al. (1998, 1999) and Emenius et al. (2004) might explain why they could not find an association between ventilation rate and health, in contrast to our study on homes with lower ventilation rates. Associations between ventilation rates and health effects may occur only when the air change rate is below 0.5 ach. However, in the Norwegian study, ventilation rate was found to be an effect modifier of risks. With low-ventilation rate the risks associated with moisture problems, and vinyl floor and wall materials in the building increased (Öie et al., 1999).

Many indoor-generated exposures will be increased in buildings with a low-ventilation rate. Furthermore, a low-ventilation rate increases the time for indoor air reactions of, e.g. ozone and terpenes with formation of, e.g. free radicals and formaldehyde (Weschler and Shields, 2000).

A reduced ventilation rate also means increased indoor air humidity, and therefore a risk of increased infestation of house dust mites (Emenius et al., 1998; Harving et al., 1994; Sundell et al., 1994; Warner et al., 2000). House dust mite exposure is a well-known risk for sensitization and symptoms among mite sensitized persons (Eggleson et al., 1998; Holm et al., 1999; Nahm et al., 1998; Ricci et al., 1999; Sporik et al., 1999; Warner et al., 1999).

The lack of an association between ventilation rate and atopic status of the children indicates that there are no immunological mechanisms involved. Instead, a low-ventilation rate could be seen as a risk factor for irritation.

Design of the study

The second phase of the DBH-study is per definition not a case-control study, but a case non-case study of all persons with prevalent symptoms at two separate periods 1.5 years apart. This means that the risk estimates are not reflecting incident cases but severe prevalent cases. Hence, the risks associated to any of the factors found in this study are associated to duration/severity of the disease rather than the induction of disease. Although this is a theoretical issue of concern the public health effect of this is negligible, since the prevalent severe cases are the main burden of society.

To be included as a 'case' a child was required to have at least two symptoms. Consequently, this study was not fine-tuned to examine associations between building factors and *single* symptoms (i.e. asthma, rhinitis, or eczema). However, even if the design is suboptimal, meaning harder to find associations between single symptoms and exposures, the associations between selected building factors and single symptoms are meaningful and possibly under estimates true associations.

Selection bias

The selection process for cases and controls has been analyzed elsewhere (Bornehag et al., unpublished). Some potential selection biases were identified (for participating children/families). Factors associated with participating were more health problem in the case families, more health-related lifestyle factors such as non-smoking parents and a higher socio economic status of the family. However, no obvious selection bias regarding ventilation factors could be found.

The associations shown between home ventilation and the health effects studied are rather weak and several associations did not reach statistical significance. In crude analyses, significant associations were found but in adjusted analyses the estimated risks were reduced and did not reach significance. One reason for non-significant associations could be a low-statistical power due to a small sample size. However, the reduced estimated risks indicate that there are other factors (covarying with ventilation rate) of importance for allergic symptoms among children. Thus, the hypothesis that low-ventilation rates in homes increase the risk of allergic symptoms among children could not be rejected.

Acknowledgements

The study was supported by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas), Swedish Asthma and Allergy Association's Research Foundation, and the Swedish Foundation for Health Care Sciences and Allergy Research. We also wish to express our thanks to Hans Stymne, Department of Built Environment, University of Gävle, Sweden, and Carl-Axel Boman, Pentiaq AB, Gävle, Sweden, for analysis for the passive tracer gas measurements of ventilation.

References

- Bornehag, C.G., Sundell, J. and Sigsgaard, T. (2004a) Dampness in buildings and health (DBH). Report from an on-going epidemiological investigation on the association between indoor environmental factors and health effects among children in Sweden, *Indoor Air*, **14**(Suppl. 7), 59–66.
- Bornehag, C.G., Sundell, J., Hagerhed-Engman, L., Sigsgaard, T., Janson, S., Aberg, N. and the DBH-study group (2004b) "Dampness" at home and its association with airway, nose and skin symptoms among 10 851 preschool children in Sweden: a cross sectional study, *Indoor Air*, doi 10.1111/j.1600-0668.2004.00306.x.
- Bornehag, C.G., Sundell, J., Weschler, C.J., Sigsgaard, T., Lundgren, B., Hasselgren, M. and Hagerhed-Engman, L. (2004c) Allergic symptoms and asthma among children are associated with phthalates in dust from their homes: a nested case-control study, *Environ. Health Perspect.*, **112**, 1393–1397.
- Eggleston, P.A., Rosenstreich, D., Lynn, H., Gergen, P., Baker, D., Kattan, M., Mortimer, K.M., Mitchell, H., Ownby, D., Slavin, R. and Malveaux, F. (1998) Relationship of indoor allergen exposure to skin test sensitivity in inner-city children with asthma, *J. Allergy Clin. Immunol.*, **102**(4 Pt 1), 563–570.
- Emenius, G., Egmar, A.C. and Wickman, M. (1998) Mechanical ventilation protects one-storey single-dwelling houses against increased air humidity, domestic mite allergens and indoor pollutants in a cold climate region, *Clin. Exp. Allergy*, **28**, 1389–1396.
- Emenius, G., Svartengren, M., Korsgaard, J., Nordvall, L., Pershagen, G. and Wickman, M. (2004) Building characteristics, indoor air quality and recurrent wheezing in very young children (BAMSE), *Indoor Air*, **14**, 34–42.
- Harving, H., Korsgaard, J. and Dahl, R. (1994) Clinical efficacy of reduction in house-dust mite exposure in specially designed, mechanically ventilated "healthy" homes, *Allergy*, **49**, 866–870.
- Holm, L., van Hage-Hamsten, M., Ohman, S. and Scheynius, A. (1999) Sensitization to allergens of house-dust mite in adults with atopic dermatitis in a cold temperature region, *Allergy*, **54**, 708–715.
- Nahm, D.K., Park, H.S., Kim, C.W., Park, J.W. and Hong, C.S. (1998) Seasonal variation of IgG subclass antibodies to house dust mite in sera from mite-sensitive asthmatic patients, *Ann. Allergy Asthma Immunol.*, **80**, 411–415.
- Norlén, U. and Andersson, K. (1995) Indoor climate in Swedish dwellings. In: *Proceedings of Healthy Buildings '95*, Vol. 1, 393–401.
- Nordtest (1997) *Ventilation: Local Mean Age Of Air – Homogenous Emission Techniques. Nordtest Method NT VVS 118*. Finland, Nordtest.
- Öie, L., Stymne, H., Boman, C.A. and Hellstrand, V. (1998) The ventilation rate of 344 Oslo residences, *Indoor Air*, **8**, 190–196.
- Öie, L., Nafstad, P., Botten, G., Magnus, P., Jaakkola, J.K. (1999) Ventilation in homes and bronchial obstruction in young children, *Epidemiology*, **10**, 294–299.
- Ricci, G., Patrizi, A., Specchia, F., Menna, L., Bottau, P., D'Angelo, V. and Masi, M. (1999) Mite allergen (Der p 1) levels in houses of children with atopic dermatitis: the relationship with allergometric tests, *Br. J. Dermatol.*, **140**, 651–655.
- Seppänen, O. and Fisk, W.J. (2002) Association of ventilation system type with SBS symptoms in office workers, *Indoor Air*, **12**, 98–112.
- Sporik, R., Squillace, S.P., Ingram, J.M., Rakes, G., Honsinger, R.W. and Platts-Mills, T.A. (1999) Mite, cat, and cockroach exposure, allergen sensitisation, and asthma in children: a case-control study in three schools, *Thorax*, **54**, 675–680.
- Stymne, H., Boman, C.A. and Kronvall, J. (1994) Measuring ventilation rates in the Swedish housing stock, *Build. Environ.*, **29**, 373–379.
- Sundell, J. (1994) On the association between building ventilation characteristics, some indoor environmental exposures, some allergic manifestations and subjective symptom reports, *Indoor Air*, Suppl. 2, 94.
- Sundell, J., Wickman, M., Pershagen, G. and Nordvall, L. (1994) Ventilation in homes infested by house-dust mites, *Allergy*, **50**, 106–112.
- Wargocki, P., Sundell, J., Bischof, W., Brundrett, G., Fanger, P.O., Gyntelberg, F., Hanssen, S.O., Harrison, P., Pickering, A., Seppänen, O. and Wouters, P. (2002) Ventilation and health in non-industrial indoor environments: report from a European multidisciplinary scientific consensus meeting (EUROVEN), *Indoor Air*, **12**, 113–128.
- Warner, A., Bostrom, S., Moller, C. and Kjellman, N.I. (1999) Mite fauna in the home and sensitivity to house-dust and storage mites, *Allergy*, **54**, 681–690.
- Warner, J.A., Frederick, J.M., Bryant, T.N., Wiech, C., Raw, G.J., Hunter, C., Stephen, F.R., McIntyre, D.A. and Warner, J.O. (2000) Mechanical ventilation and high-efficiency vacuum cleaning: a combined strategy of mite and mite allergen reduction in the control of mite-sensitive asthma, *J. Allergy Clin. Immunol.*, **105**(1 Pt 1), 75–82.
- Weschler, C.J. and Shields, H.C. (2000) The influence of ventilation on reactions among indoor pollutants: modeling and experimental observations, *Indoor Air*, **10**, 92–100.