

Ventilation and dampness in dorms and their associations with allergy among college students in China: a case–control study

Abstract To study the associations between dorm environment and occupants' health, a nested case–control study on 348 college students was carried out in 2006–2007 at Tianjin University, China. Two hundred and twenty-three dorm rooms where the 'cases' and 'controls' resided were inspected. Measured variables were ventilation rate, air temperature, and relative humidity indoors. Allergic symptoms in the last 12 months were self-reported by occupants. Adjusted odds ratios (AORs) of a 'localized moldy smell/moisture indicator' in 'special places' (e.g., in a room corner or close to the radiator under the window) for wheezing was 3.56 [95% Confident Interval (CI): 1.56–8.14] and for rhinitis 2.81 (95% CI: 1.32–5.97). The AOR of a low air change rate (below the median value of 0.7/h) for wheezing was 2.28 (95% CI: 1.38–3.75) and for dry cough 2.26 (95% CI: 1.08–4.75). The prevalence of students with allergic symptoms in dorm rooms decreased with increasing ventilation rate. The combination of a 'localized moldy/moisture indicator' and a low air change rate significantly increased the AOR of case status to 13.35 (95% CI: 3.73–47.83), compared to the reference condition with no-dampness and high ventilation rate (above the median). This supports the hypothesis that ventilation rate is an effect modifier for moisture problems and indoor pollutants.

**Y. Sun^{1,2}, Y. Zhang², L. Bao²,
Z. Fan², J. Sundell^{3,4,5}**

¹Department of Architecture Engineering, The Pennsylvania State University, PA, USA, ²School of Environmental Science and Engineering, Tianjin University, Tianjin, China, ³International Center for Indoor Environment and Energy, Technical University of Denmark, Lyngby, Denmark, ⁴Department of Building Science, School of Architecture, Tsinghua University, Beijing, China, ⁵The Faculty of Urban Construction and Environmental Engineering, Chongqing University, Chongqing, China

Key words: Ventilation; Dampness; Asthma and allergy; Building characteristics; Dorm environment; College students.

Yuxia Sun
227 Engineering Unit A,
University Park, PA 16802,
USA
Tel.: +1-814-863-8313
Fax: +1-814-863-4789
e-mail: ysun@engr.psu.edu; syxzh@yahoo.com.cn

Received for review 21 December 2009. Accepted for publication 15 October 2010.

Practical Implications

Dorm rooms, a kind of residential environment for students, may be more polluted than the home environment. This is especially the case in developing countries like China, where dorms tend to be more crowded. In dorms, a low ventilation rate is a risk factor for asthma and allergy. Sufficient fresh outdoor air should be provided to students' dormitories by controlled ventilation. Mechanical ventilation system are often needed in regions such as north China, as the buildings are now 'tight' and opening of windows is not a solution during the cold winter.

Introduction

Since 1970s, with the increased costs for energy, buildings and homes are becoming more and more tight. Without mechanical ventilation, this means a decrease in ventilation rates. Such a decrease coincides in time with the increase in allergic diseases. A multidisciplinary scientific literature review (EURO-

VEN) concluded that outdoor air supply rates below 25 l/(s·person) increased the risk of sick building syndrome (SBS) symptoms among occupants of office buildings (Wargocki et al., 2002). Weschler and Shields (2000) reported that a low ventilation rate increased the reaction time for ozone and volatile organic compounds (VOC) to form more health relevant pollutants. Sundell et al. (1995) found that elevated

concentrations of house dust-mite allergens in mattress and floor dust were associated with a low ventilation rate. Many international and multidisciplinary reviews have shown that dampness in buildings is strongly associated to health problems like asthma and respiratory symptoms, all over the world (Bornehag et al., 2001), in particular in combination with a low ventilation rate (Hägerhad-Engman et al., 2009).

In China, a dormitory is a more crowded environment for students than their homes. In average, four people share a 20-m² dorm room. The wet clothes of the students are usually aired in building corridors or in enclosed balconies. The aim of this study is to analyze the associations between ventilation and dampness in dorm environment and asthma and allergic symptoms among college students in China.

Materials and methods

Subjects

Prior to the present case-control study, a cross-sectional study was carried out from February 21 to June 10, 2006, at Tianjin University campus in China (Sun et al., 2009). Health conditions of the students were self-reported in questionnaires. The questionnaires were mainly the same as earlier used in Sweden and Bulgaria for homes (Bornehag, et al., 2005a; Naydenov et al., 2008), with minor changes because of the dorm environment. The medical part of the questionnaire follows the ISAAC questionnaire (Asher et al., 1995). A nested case-control study was launched from May 9, 2006 to April 14, 2007. 'Cases' were students who had reported at least two symptoms of asthma, rhinitis, and atopic eczema, while 'controls' reported no such symptoms. The questions on asthma and allergic symptoms were as follows,

Asthma symptoms. Have you had wheezing or whistling in the chest in the last 12 months?

In the last 12 months, have you had a dry cough at night for more than 2 weeks, apart from a cough associated with a cold or chest infection?

Rhinitis symptoms. In the last 12 months, have you had a problem with sneezing, or a runny, or a blocked nose when you did not have a cold or flu?

In the last 12 months, have you had a problem with sneezing, a runny or a blocked nose, or itchy-watery eyes after coming in contact with furred animals?

In the last 12 months, have you had a problem with sneezing, a runny or a blocked nose, or itchy-watery eyes after coming in contact with pollen?

Eczema symptom. Have you had itchy rash (eczema symptom) at any time in the last 12 months?

One thousand and six students in the prior cross-sectional study met the definition of 'cases' and 'controls'. Three hundred and forty-eight students were invited and took part in the nested case-control study. They lived in 223 dorm rooms that were located on different floors and dorm buildings. The mean age of all subjects was 23 years. These students had a similar living routine and style, i.e., lecture at a teaching building, food in a student cafeteria, and rest in dorm rooms (at least 8 h). All the participants had lived in their present dorms for more than 1 year and they did not move during the process of the case-control study.

Physical parameter measurements and building investigations

Two trained inspectors visited a dorm room making observations and placing the indoor air quality monitor PS 31 (<http://www.sensotron.pl>) for 24-h measurements of CO₂, air temperature, and relative humidity. Before measurements, the monitors were calibrated at the International Center for Indoor Environment and Energy, Technical University of Denmark. The air change rate of the dorm room was calculated based on analyses of a build-up period of metabolic CO₂ produced by occupants when they slept at night (1:00–8:00 am), by using the method proposed by Stavova (2004) with an uncertainty <5%. Each dorm room is one simple bedroom, which can be treated as a single zone. The individual step increase in CO₂ concentration (Δc) between two measurements performed with time interval of $\Delta\tau$ in a point can be expressed from the instantaneous flow rate equation as:

$$\Delta c = \frac{\Delta\tau}{V_{\text{zone}}} \cdot [F - N \cdot V_{\text{zone}} \cdot (c_1 - c_{\text{out}})]$$

where,

V_{zone} – Volume of the zone (m³);

F – Emission rate (m³/s). It depends on the level of activity (M , met), height (H , m), weight (W , kg), and respiratory quotient (RQ, 0.83) (Persily, 1997):

$$F = \text{RQ} \frac{0.00056028 \cdot H^{0.725} \cdot W^{0.425} \cdot M}{0.23 \cdot \text{RQ} + 0.77};$$

N – Air change rate of the zone (ach);

c_1 – CO₂ concentration measured at the beginning of the time interval $\Delta\tau$ (m³/m³);

c_{out} – Outdoor CO₂ concentration (m³/m³).

The concentration c_2 at the end of the time interval can be computed as the sum of the initial concentration (c_1) and the unit increase in concentration Δc . The calculation might be repeated for each consequent time

interval so that a theoretical exponential curve can be constructed. Then this theoretical curve is fitted to the measured data using the least square method. When the iterating process is finished, the best fitting air change rate and emission rate of CO₂ are found. Each dorm room was measured two times, i.e., in the summer (period from May 9 to July 7, 2006) and in the winter (period from December 5, 2006 to April 14, 2007). The outdoor CO₂ concentration and meteorological parameters were also measured at the campus, during the same time. The CO₂ concentrations in corridors were not measured. However, the windows in corridors were all the time open to outdoors, especially during summer.

On entering the dorm room, one inspector assessed the first-hand impression of stuffy and moldy odor. Signs of moisture such as moldy/damp stains on walls or ceilings, and peeling of wall covering were noted. The 'localized moldy odor/moisture indicators,' e.g., at the corner of the room, around the radiator under the window were perceived. Inspectors were blinded to the health status of occupants.

Information on building characteristics, e.g., building foundation, roof style, building outer wall material, building maintenance, window type, and floor covering were obtained in the inspection. Building construction period was informed by the dorm management center of Tianjin University.

Statistical analysis

Air change rates indoors were not normally distributed; thus, their associations with inspected dampness and building characteristics were studied by a non-parametric Mann–Whitney *U*-test (Bernard, 2004). The associations between building characteristics, e.g., building construction period, roof style, window type and floor covering, and dampness were analyzed in multiple logistic regression models using forward elimination technique. The criterion for significance in the procedures was $P < 0.05$. The odds ratios (OR) of dorm environmental factors (e.g., dampness and air change rate) for asthma and allergic symptoms in college students were evaluated in logistic regression models with 95% confident interval (CI). The odds ratios were adjusted for gender, age, allergy of any family member, smoking in the last 3 months, passive smoking, pet indoors, and building construction period. A 'room allergic symptom index' was defined as the ratio of reported symptoms to the number of respondents in each room. Statistical Package for the Social Sciences (SPSS) software 15.0 (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis.

The present study was approved by the dormitory management center at Tianjin University, Tianjin City, China.

Table 1 Demographic information and building character for control and case subjects

	Control, 205	Case, 143	
	<i>n</i> (%)	<i>n</i> (%)	<i>P</i> value ^a
Sex			
Female	91 (44.4)	51 (35.7)	0.103
Male	114 (55.6)	92 (64.3)	
Age			
≤ 23	96 (58.5)	63 (54.8)	0.735
24–26	51 (31.1)	37 (32.2)	
≥ 27	17 (10.4)	15 (13.0)	
Smoker ^b			
No	186 (90.7)	118 (84.9)	0.097
Yes	19 (9.3)	21 (15.1)	
Atopy ^c			
No	197 (96.6)	113 (81.9)	0.000
Yes	7 (3.4)	25 (18.1)	
Building construction period			
1940–1960	35 (17.1)	26 (18.2)	0.301
1977–1983	32 (15.6)	14 (9.8)	
1993–1999	33 (16.1)	31 (21.7)	
After 2000	105 (51.2)	72 (50.3)	
Foundation			
Basement	105 (51.2)	72 (50.3)	0.873
Concrete slab	100 (48.8)	71 (49.7)	
Roof style			
Flat	150 (73.2)	105 (73.4)	0.958
Gable	55 (26.8)	38 (26.6)	
Outer wall material			
Concrete	112 (54.6)	79 (55.2)	0.910
Brick	93 (45.4)	64 (44.8)	
Window type			
Wooden	57 (27.8)	39 (27.5)	0.322
PVC	148 (72.2)	101 (71.1)	
Iron	0 (0.0)	2 (1.4)	
Floor covering			
Stone	121 (59.0)	86 (60.1)	0.835
Cement	84 (41.0)	57 (39.9)	

^aPearson Chi-square test.

^bSmoking in the last 3 months prior to the survey.

^cAny family member ever had asthma and allergy.

Results

The demographic information and building characteristics for control and case subjects are shown in Table 1. The 'cases' and 'controls' lived in 223 dorm rooms. Ninety-eight dorm rooms had 'cases' and 112 had 'controls'. Thirteen dorm rooms had both 'cases' and 'controls'. Among the 143 cases, 89 had asthma and rhinitis symptoms in the last 12 months, 2 had asthma and eczema symptoms, 12 had rhinitis and eczema symptoms, and 40 had symptoms of asthma, rhinitis, and eczema.

All the inspected rooms had natural ventilation by opening windows/doors. In summer, doors/windows of dorm rooms are fully opened because of the hot weather. The air change rates of rooms calculated based on the summer measurement varied significantly, from 0.29 to 29.55/h, with a median of 6.72/h. The air change rate in the heating season (from December 5, 2006 to April 14, 2007) varied from 0.05 to 6.93/h, with

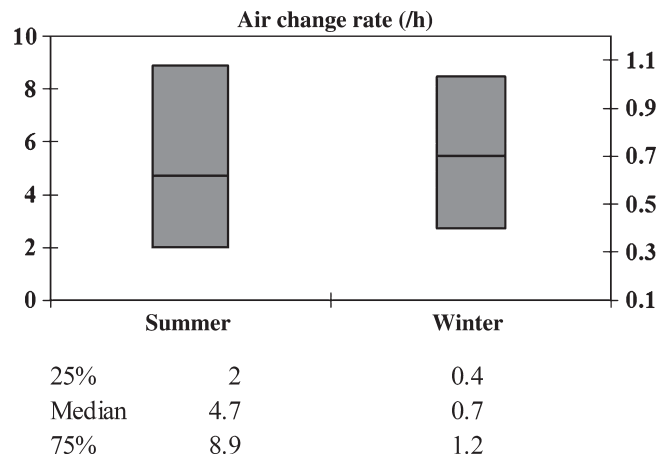


Fig. 1 Box plot of air change rates in dorm rooms calculated based on the measurements in summer and winter. Left axis is the air change rate in summer, while right axis is in winter.

a median of 0.71/h. Thirty-nine percentage of the rooms had an air change rate <0.5 /h and 90% had airflow rate per person (= air change rate $\times$ volume of zone/number of occupants) <8.3 l/(s $\cdot$ person) during the heating season. In the heating season, when doors and windows were closed at night (1:00–8:00 am), the average CO₂ concentration was 1483 ppm for 6-person-room, 1021 ppm for 4-person-room, and 1011 ppm for 3-person-room. The box plot of air change rates in summer (left axis) and winter (right axis) is shown in Figure 1.

In winter measurement, the air change rate in rooms with PVC frame window was significantly lower than that of wooden frame window, as shown in Figure 2. The frequency and percentage of dampness indicators inspected in summer and winter are shown in Table 2.

There were no significant associations between air change rate (/h) and dampness problems. However, the airflow rate per person, l/(s $\cdot$ person), were significantly lower during the heating season in rooms with obvious stuffy odors, compared to rooms with no such percep-

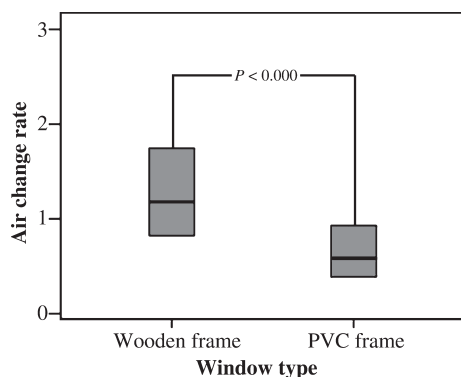


Fig. 2 Comparison of air change rates (/h) in rooms with different window types

Table 2 Frequency and percentage of dampness indicators inspected in summer and winter

	Summer	Winter
	<i>n</i> (%)	<i>n</i> (%)
Stuffy ^a	105 (36)	122 (74)
Moldy ^b	29 (10)	8 (5)
Moldy, local ^c	125 (43)	51 (31)
Moisture ^d	160 (55)	8 (5)

^aFirst-hand impression of stuffy smell indoors perceived by inspectors.

^bFirst-hand impression of moldy smell indoors perceived by inspectors.

^cMoldy smell in local places, e.g., at room corner/under radiator near windows perceived by inspectors.

^dMoldy/damp stains on walls or ceilings, or peeling of wall covering.

tion ($P < 0.05$). In winter inspections, the stuffy smell was perceived more often in buildings constructed after 2000 (OR: 3.56; 95% CI: 1.71–7.38). The odds ratios of PVC frame window for stuffy smell and localized moldy smell were 4.41 (95% CI: 2.00–9.74) and 3.97 (95% CI: 1.61–9.81), respectively.

In the summer inspection, the moldy smell/moisture sign in ‘local places’ indoors was significantly associated with rhinitis (AOR: 1.42; 95% CI: 1.02–1.97). The moldy smell perceived by inspectors on entering the room had a significant negative association with eczema symptom. However, this was not found for winter inspections.

The associations between dampness inspected in winter (from December 5, 2006 to April 14, 2007) and occupants’ health were analyzed in logistic regression models, as shown in Table 3. Subjects in rooms with inspected stuffy smell reported significantly more often wheezing, while a moldy smell/moisture sign in ‘local place’ was significantly positively associated with wheezing and rhinitis.

The adjusted odds ratios of low air change rate in summer for allergic symptoms among college students did not reach significance, while in winter, an air change rate below the median was significantly associated with an increased prevalence of wheezing and dry cough, as shown in Table 4.

The ‘room allergic symptom index’ is normally distributed. Twenty-four percent of the rooms had at least two allergic symptoms for each occupant. Figure 3 shows the decreasing trend of the room allergic symptom index with the increment of air change rate in winter. Rooms with only one respondent were not included in this analysis.

Figure 4 indicates that the combination of a low air change rate in winter and moldy smell/moisture in a ‘local place’ increased the adjusted odd ratios (AOR) for case status to 13.35 (3.73–47.83, 95% CI). The AORs for wheezing and rhinitis increased to 6.56 (95% CI: 2.33–18.51) and 4.62 (95% CI: 1.73–12.32), respectively, compared to the reference condition with high air change rate but no such dampness problem.

Table 3 Logistic regression analysis on association between occupants' health and dorm dampness indicators inspected in winter case-control study (December 5, 2006–April 14, 2007)

	Control, 205 <i>n</i> (%)	Case, 143 <i>n</i> (%)	Adjusted Odds Ratios (95% CI) ^a				
			Cases, 143	Wheeze, 138	Dry cough, 61	Rhinitis, 211	Eczema symptom, 60
Stuffy ^b	103 (71.5)	80 (77.7)	2.48 (1.15, 5.38)	2.90 (1.40, 6.03)	1.51 (0.55, 4.13)	1.05 (0.60, 1.85)	1.80 (0.48, 6.82)
<i>P</i> ^c	0.277						
Moldy/moisture in local place ^d	26 (18.1)	42 (40.8)	5.04 (2.05, 12.38)	3.56 (1.56, 8.14)	2.54 (0.79, 8.18)	2.81 (1.32, 5.97)	2.24 (0.50, 10.06)
<i>P</i>	0.000						

^aAdjusted for gender, age, pets indoors, passive smoking, smoking in the last 3 months, whether family member ever had asthma and allergy, and building construction period.

^bFirst-hand impression of stuffy smell indoors perceived by inspectors: No versus Yes.

^cPearson Chi-square test.

^dMoldy smell/moisture sign in local place, e.g., at room corner/around radiator under window perceived by inspectors: No versus Yes.

Table 4 Logistic regression analysis on association between air change rate in dorm rooms in winter and occupants' health

Adjusted Odds Ratios (95% CI) ^a				
Cases	Wheezing	Dry cough	Rhinitis	Eczema symptom
ACR (/h) (below vs. above median)				
2.00 (1.16, 3.45)*	2.28 (1.38, 3.75)**	2.26 (1.08, 4.75)*	1.20 (0.78, 1.86)	1.44 (0.60, 3.43)

*0.01 < *P* < 0.05; **0.001 < *P* < 0.01.

^aAdjusted for gender, age, pets indoors, passive smoking, smoking in the last 3 months, whether family member ever had asthma and allergy, and building construction period.

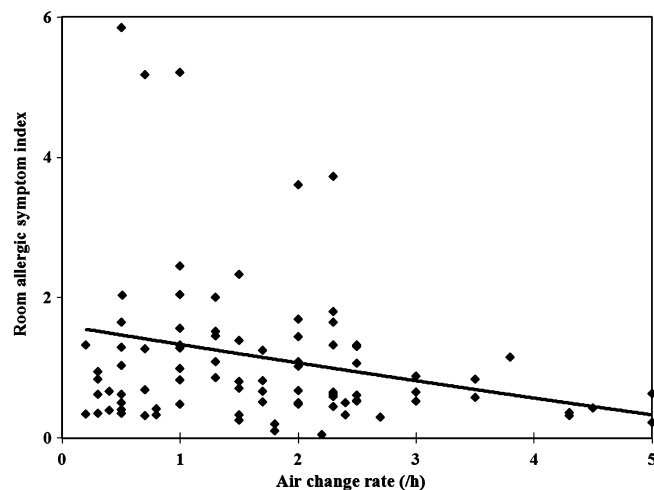


Fig. 3 Relationship between mean numbers of allergic symptoms among occupants in each room and air change rate in winter. Rooms with only one respondent were not included

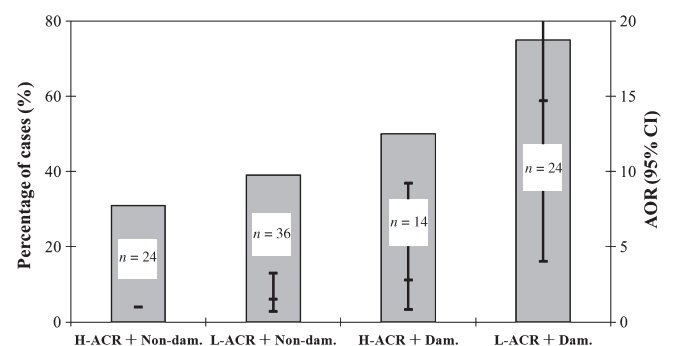


Fig. 4 Association between case status and combination of 'local' dampness and air change rate of dorm rooms in winter. H-ACR + Non-dam: air change rate above median without moldy smell/moisture sign in 'local places,' e.g., in room corner/around radiator under window. L-ACR + Dam: Air change rate below median with moldy smell in local places. AOR: Adjusted for gender, age, pets indoors, passive smoking, smoking in the last 3 months, whether family member ever had asthma and allergy, building construction period

Discussion

At Tianjin University, on average, six bachelors, four masters, or three PhD students share one dorm room of 20 m². Such dorm environment typically represents the living condition and indoor environmental exposure of college students in China.

The high response rate (74%) in the previous cross-sectional study means a sufficient internal validity for the present case-control study. There were no significant differences of gender and age between case and

control subjects. In China, the general public is not educated about problems related to dampness/ventilation. Therefore, the results found in the present study should not be affected by a possible bias of selection or information. During the summer and winter measurement, the outdoor air temperature, relative humidity, CO₂ concentration, and meteorological parameters were also monitored. Measurements under abnormal weather conditions were excluded from the analysis.

The air change rates in rooms with PVC frame windows were significantly lower than for rooms with wooden frame window, which indicates that PVC windows have made the building tighter. A study carried out by Platts-Mills et al. (1996) found that modern homes and offices were much better insulated than was previously the case. PVC frame windows are installed in new constructed dorm buildings after 2000 to save energy. In such tighter buildings, the pollutants and moisture content indoors cannot be removed by outdoor airflows through opening of windows and doors in a cold climate. Consequently, a stuffy smell was perceived more often by visitors. Especially in winter, when doors and windows were closed, more rooms had a perceived stuffy smell (36% in summer vs. 74% in winter). An inverse relationship between a stuffy smell and airflow rate per person was found.

In summer inspections, more moisture spots and moldy smell were found compared to in winter inspections. In summer, the outdoor air relative humidity was high, often up to 80%, and students washed and dried clothes more often compared to in winter. Especially for the 'new' buildings, clothes are always air-dried inside the enclosed balcony of the dorm room.

In ASHRAE Standard 62-1999 (ASHRAE, 1999), the airflow rate per person for dormitory sleeping areas was 8 l/ (s*person). The outdoor airflow rate required in the Indoor Air Quality Standard of China is 8.3 l/ (s*person) and the day average volume concentration of CO₂ was required to be no >0.1% (GB/T 18883-2002, 2002). In the present study, 90% of dorm rooms measured in winter had a low airflow rate per person [$<8.3 \text{ l}/(\text{s*person})$]. The CO₂ concentration in the corridor was not measured. Thus, the fresh outdoor airflow rate may be even lower than the calculated value in cases where the windows in the corridors were not open. Bornehag et al. (2005b) measured air change rate in 390 homes in Sweden and found a strong dose-response relationship between air change rate and asthma and allergy. In the present study, when the air change rate in winter decreased, the prevalence of wheezing and dry cough among college students increased significantly. Average numbers of allergic symptoms in dorm rooms decreased with increased ventilation rate. A low ventilation rate will result in high CO₂ concentrations. A recent study on associations between CO₂ concentrations in classrooms and asthma and respiratory symptoms among pupils showed that the current asthma prevalence decreased from 4.2% to 1.4% when the CO₂ concentration decreased from 1001–1555 to 595–800 ppm

(Mi et al., 2006). A low ventilation rate leads to higher indoor air pollution, higher relative humidity, and more house dust-mites and mold. In Nordic countries, the increase in asthma and allergy is coincident with energy-saving campaigns, during which buildings were tightened to reduce energy usage (Sundell, 1994).

When a low air change rate and localized moldy smell were combined, their added negative effects on wheeze, rhinitis, and case status of students were at least doubled, compared to the effects of single risk factors. In a nested case-control study of 400 Swedish children, a low ventilation rate in combination with moldy odor along the skirting board increased the risk for asthma and allergy (Hägerhad-Engman et al., 2009). The present dorm study confirmed the hypothesis that ventilation rate is an effect modifier for moisture problems and indoor pollutants.

Conclusions

- Outdoor air change rate was significantly lower in rooms with PVC frame windows. A stuffy smell was perceived more often in rooms with a low air change rate.
- A low air change rate was a risk factor for allergic symptoms in college students. Average number of allergic symptoms in dorm rooms decreased with increased ventilation rate. Sufficient fresh outdoor air should be provided to students' dormitories by controlled airflow through mechanical ventilation system.
- A moldy smell/moisture sign in 'local places' indoors, e.g., at room corners or around the radiator under a window had a significant negative association to wheezing and rhinitis among college students, especially in combination with a low ventilation rate.

Acknowledgements

We appreciate all the students of Tianjin University who participated in this study, Dr. Kiril Naydenov (Technical University of Denmark, Denmark) for calibration of air quality monitors and communication in this case-control study, Ph.D. candidate Petra Stavova (Technical University of Denmark, Denmark) for her assistance in ventilation rate calculations, Dr. Fredericka Brown (University of Texas at Tyler, USA) for reviewing the manuscript.

References

- Asher, M.I., Keil, U., Anderson, H.R., Beasley, R., Crane, J., Martinez, F., Mitchel, E.A., Pearce, N., Sibbald, B., Stewart, A.W., Strachan, D., Weiland, S.K. and Williams, H.C. (1995) International study of asthma and allergies in childhood (ISAAC), rationale and methods, *Eur. Respir. J.*, **8**, 483–491.
- ASHRAE Standard 62-1999. (1999) Ventilation for acceptable indoor air quality. *American Society of Heating, Atlanta, GA, Refrigerating and Air-Conditioning Engineers.*
- Bernard, R. (2004) *Fundamentals of Biostatistics*, 5th edn, Boston, Duxbury Press.
- Bornehag, C.G., Blomquist, G., Gyntelberg, F., Jarvholm, B., Malmberg, P., Nordvall, L., Nielsen, A., Pershagen, G. and Sundell, J. (2001) Dampness in buildings and health, *Indoor Air*, **11**, 72–86.
- Bornehag, C.G., Sundell, J., Hagerhed-Engman, L., Sigsgaard, T., Janson, S., Aberg, N. and the DBH study group. (2005a) 'Dampness' at home and its association with airway, nose and skin symptoms among 10851 preschool children in Sweden: a cross-sectional study, *Indoor Air*, **15**, 48–55.
- Bornehag, C.G., Sundell, J., Hägerhed-Engman, L. and Sigsgaard, T. (2005b) Association between ventilation rates in 390 Swedish homes and allergic symptoms in children, *Indoor Air*, **15**, 275–280.
- GB/T 18883-2002. (2002) *Indoor Air Quality Standard*, Beijing, China, National Environment Agency.
- Hägerhad-Engman, L., Sigsgaard, T., Samuelson, I., Sundell, J., Janson, S. and Bornehag, C.G.. (2009) Low home ventilation rate in combination with moldy odor from the building structure increase the risk for allergic symptoms in children, *Indoor Air*, **19**, 184–192.
- Mi, Y.H., Norbäck, D., Tao, J., Mi, Y.L. and Ferm, M. (2006) Current asthma and respiratory symptoms among pupils in Shanghai, China: influence of building ventilation, nitrogen dioxide, ozone, and formaldehyde in classrooms, *Indoor Air*, **16**, 454–464.
- Naydenov, K., Melikov, A., Markov, D., Stankov, P., Bornehag, C.G. and Sundell, J. (2008) A comparison between occupants' and inspectors' reports on home dampness and their association with the health of children: the ALL-HOME study, *Build. Environ.*, **43**, 1840–1849.
- Persily, K.A. (1997) Evaluating building IAQ and ventilation with indoor carbon dioxide, *ASHRAE Trans.*, **103**, 193–204.
- Platts-Mills, T.A.E., Woodfolk, J.A., Chapman, M.D. and Heymann, P.W. (1996) Changing concepts of allergic disease: the attempt to keep up with real changes in lifestyles, *J. Allergy Clin. Immunol.*, **98**, S297–S306.
- Stavova, P. (2004) *A Method for Air Change Rate Measurements in Dwellings Based on Carbon Dioxide Produced by People*, Master Thesis, Denmark, Technical University of Denmark.
- Sun, Y.X., Zhang, Y.F., Sundell, J., Fan, Z.G. and Bao, L.J. (2009) Dampness at dorm and its associations with allergy and airway infection among college students in China: a cross-sectional study, *Indoor Air*, **19**, 174–182.
- Sundell, J. (1994) On the association between building ventilation characteristics, some indoor environmental exposures, some allergic manifestations and subjective symptom reports, *Indoor Air*, **4**(Suppl. 2), 4–79.
- Sundell, J., Wickman, M., Pershagen, G. and Nordwell, S.L. (1995) 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.
- 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.