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Housing characteristics, home environmental factors, and pulmonary function deficit in Chinese children: Results from the Seven Northeast Cities (SNEC) Study

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Abstract

To assess the effects of housing characteristics and home environmental factors on lung function of Chinese children, 6740 children (aged 6–16 years) were recruited from seven cities in Northeast China in 2012. Performance of lung function was determined by comparison of forced vital capacity (FVC), forced expiratory volume (FEV1), peak expiratory flow (PEF), and maximal mid-expiratory flow (MMEF). Multivariate regression models were used to evaluate the associations with lung function deficit. The results showed that housing conditions were associated with lung function deficit in children. The adjusted odds ratios were 0.47 (95% CI: 0.26–0.83) for FVC for "ping-fang" housing compared with "dan-yuan-lou-fang" housing and 2.90 (95% CI: 2.43–3.47) for FEV1 with home renovations completed within two years compared with counterparts. The linear regression models consistently showed a significant association of housing conditions and home environmental factors with lung function measurements across subjects. A residence taller than seven stories was negatively associated with FEV1 ($\beta = -55$; 95% CI: −97 to −13). In conclusion, housing conditions and home environmental factors are particularly important to the development of lung function and respiratory health in children. These factors are concerning and action should be taken to improve them.

Key words: housing characteristics, home environment, lung function, children, China

Introduction

The World Health Organization (WHO) estimates that there are more than 3.8 million annual deaths attributable to indoor air pollution, with a great burden of disease in developing and developed countries (Lim et al. 2012; Thomas et al. 2015; Asikainen et al. 2016). Associations between exposure to various forms of indoor air pollution and lung function outcomes in developed countries have been previously explored (Mendell et al. 2011; Lane et al. 2013; Khreis et al. 2017; Park et al. 2017). For instance, living in a home with active mold exposure has been associated with asthma development and exacerbation as well as diagnoses of asthma, dyspnea, wheeze, cough, respiratory infection, allergic rhinitis, and other upper respiratory tract symptoms (Mendell et al. 2011). Home proximity to roadways has been used as an exposure proxy for pollutants emitted through automobile traffic (Lane et al. 2013; Khreis et al. 2017; Park et al. 2017), which has been associated with reduced lung function growth in school-aged children in the United States and Sweden (Gauderman et al. 2007; Schultz et al. 2012). Additionally, exposure to environmental tobacco smoke (ETS) (Chen et al. 2014; Hu et al. 2017; Milanzi et al. 2017) allergens is known to play a role in respiratory irritation. Potentially, exposure to endotoxins, pets, pests, and certain microorganisms could also play a similar role (Bertelsen et al. 2010).

Efforts have been made to elucidate the contribution of modern building materials and furnishings to respiratory health, although causal links have yet to be established (Hulin et al. 2012). Volatile organic compounds (VOCs) have been associated with various measures of lung dysfunction (Billionnet et al. 2011; Franck et al. 2014; Sukul et al. 2016; van Vliet et al. 2017; Yamada et al. 2017). Phthalates have also been implicated as a possible chemical exposure related to numerous developmental perturbations affecting children (Braun et al. 2013; Huang et al. 2015). Flame-retardants, common in building materials and furnishings, have been associated with poor respiratory health outcomes (Araki et al. 2014). Additionally, persistent wheeze and lung function deficits in nonatopic children have been associated with maternal exposure to household cleaning products during pregnancy (Henderson et al. 2008).

Of course, children possess an increased risk for adverse health effects associated with household air pollution because they have a higher per-minute respiratory rate, underdeveloped immune and respiratory systems, and longer home-stay relative to adults (Bennett et al. 2007; Siezen et al. 2009; McInnes et al. 2011). While numerous epidemiologic studies have assessed associations between exposure to ambient air pollution and lung function decline in children (Gauderman et al. 2002; He et al. 2010; Roy et al. 2012; Zeng et al. 2016), less is known about the adverse respiratory health outcomes associated with exposure to indoor air pollution in children. This is particularly true of those in developing countries.

Few studies have investigated adverse respiratory health effects associated with exposure to household sources of indoor air pollution in Chinese children. The hypothesis of this investigation was that housing characteristics play a role in child lung function. It examined the associations between lung function measures and exposure to various forms of indoor air pollution in school-aged Chinese children using data from the Seven Northeast Cities (SNEC) Study.

Materials and methods

Subject recruitment

A multi-site cross-sectional design was used to examine health outcomes of children in relation to their housing conditions and proximity to certain environmental factors. Participants were selected from 20 million residents of 14 cities in Liaoning Province, China. Seven cities—Shenyang, Dalian, Anshan, Fushun, Benxi, Liaoyang, and Dandong—were selected "to maximize the inter- and intra-city gradients of the pollutants of interest and also to minimize the correlation between district specific ambient pollutants" (Zeng et al. 2016). Participants were randomly selected from one to two classrooms representing each grade in one elementary and one middle school. Both schools were within one mile of a local air monitoring station. The participants included only those children who had continuously resided in their district for two or more years prior to the initiation of this study. The final sample was comprised of 3382 boys and 3358 girls.

This study was conducted according to the World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects. Ethical approval was obtained for this project from the Human Studies Committee of Sun Yat-sen University, the site of the study (Ethics Approval Number: L2014016). Written informed consent was obtained from each participant, as well as their parents, prior to data collection.

Questionnaire survey

School administrators facilitated the distribution of questionnaires and forms through trained classroom teachers. Teachers obtained written consent from the parent(s), who answered the questions. Parents were given the option to attend an evening meeting to complete the questionnaire or to complete it at home and return the responses in a provided sealed envelope. A summary description of select variables is available in Table 1. The questionnaire, in Chinese, is included in the Supplementary Material 1.

Table 1. Housing characteristics and environmental factor variables used in this study.

Characteristic	Description	Prevalence
Housing type		
Dan-yuan-lou-fang	An apartment unit in a multi-story, multi-unit building.	87.2%
Ping-fang	A one-story house, typically with a small yard.	9.8%
Other	Dormitory or any other unspecified housing type.	3.0%
Environmental factor		
Proximity to emissions	A pollution source, such as a factory or smokestack, within 100 m of a household.	37.9%
Indoor coal use	The use of coal for cooking or heating inside a household.	10.0%
Ventilation use	The use, within a household, of any of the following ventilation devices: exhaust fan, chimney, or fume hood (typically above a cook stove).	87.3%
Humidifier use	The use of humidifier devices within a household.	16.2%
Pet-keeping	Living with the following pets: dogs, cats, farm animals (including birds, chickens, ducks, or geese), and others.	21.3%
Recent home renovation	Any of the following renovations to a household within the previous 2 years: installation of linoleum floor, new paint, installation of particleboard, new furniture, new wall covering, or new suspended ceiling.	35.9%
Recent mold/water in the home	Signs of flooding, water damage, or mold growth (on any surfaces other than food) in the household in the past 12 months.	13.3%
Recent pests in the home	Exposure to pests, determined by visual confirmation of vermin (separate questions for cockroaches, mice, or rats) in the household in the past 12 months.	35.9%
ETS during the first 24 months of life	There were smokers in regular contact with the child between birth and 2 years of age, including regular visitors (e.g., grandparents or babysitters).	20.7%
ETS during pregnancy	During pregnancy, the mother was exposed to environmental tobacco smoking.	19.4%
Current ETS	Daily smoking by any individual in the household.	48.7%

Note: ETS, environmental tobacco smoking.

Lung function measurement

Body weight and body stature were measured using a standardized protocol. Body mass index (BMI) was calculated as weight in kilograms divided by stature in meters squared. Lung function data, including forced vital capacity (FVC), forced expiratory volume (FEV1), peak expiratory flow (PEF), and maximal mid-expiratory flow (MMEF), were collected using Spirolab MIR portable electronic spirometers (Rome, Italy). These spirometers have been independently evaluated in an occupational setting and found to have sensitivity and specificity values of 97.75% and 73.04%, respectively (Mehrparvar et al. 2014). The model used in this study was automatically calibrated using the manufacturer's process. Lung function data were collected per the manufacturer's recommendations by two skilled research technicians. The American Thoracic Society and the European Respiratory Society standards were used, and spirometry was performed only after the participant was able to understand and follow the provided instructions. The age range of the study participants was 6–16 years.

The children were asked to stand comfortably for the assessment and a nose clip was applied to obstruct nasal airflow during measurements. Measurements for total lung capacity and residual volume were taken. FVC and FEV1 values were recorded in milliliters and were the peak value(s) from any of three satisfactory curves when at least two of the three curves differed by no more than 5%. Corrections for body temperature and saturated pressure were applied.

EpiData Entry was used for data input and notation. Double entry verification was used to ensure quality data, which were also encrypted. Predicted lung function values were calculated from reference equations including variables of height, weight, and age (Ma et al. 2013). Lung function impairment was classified in terms of measured spirometric performances above or below predicted lung function values as follows: FEV1 < 85% of predicted, FVC < 85% of predicted, PEF < 75% of predicted, and MMEF < 75% of predicted.

Statistical analysis

Data were assessed for normality using the Shapiro–Wilk test and for homogeneity using Bartlett's test for unequal variances. Relative frequencies and differences between categorical variables were calculated using the χ^2 test. Mean ± SD and differences between continuous variables were calculated using a t-test.

In addition to reporting the exposure–response relationship by using health outcomes as continuous variables, this study evaluated whether this relationship reaches a degree of damage on lung function by using health outcomes as binary variables. For categorical lung function measurements, multilevel logistic regression was used to estimate the association between indoor air pollutants and measures of respiratory function. Specifically, the prevalence odds ratios (PORs) of respiratory function with respective 95% confidence intervals (CIs) were estimated for indoor air pollutants. The primary explanatory variables of interest for this study were: housing type, age of the home, structure of the home, floor area of residence, number of rooms, distance from traffic, pollution source near the home, pets in the home, home renovation, mold, pests, indoor coal use, ventilation device or humidifier device use, and ETS exposure. PORs were mutually adjusted for potential confounders, including age, gender, BMI, parental education, breastfeeding status, income, ETS, family history of atopy, parents as responders, and study districts. For continuous lung function measurements, we used a two-stage multiple linear regression model to estimate effects. An a priori p value of <0.05 was used to determine statistical significance for all tests. All analyses were conducted using the GLIMMIX and MIXED procedures in SAS® software (version 9.4 (SAS Institute, Cary, NC, USA)) to account for the hierarchical structure of the data (i.e., participants nested within study districts). A complete description of the analytical methods is included in the study by Dong et al. (2008).

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Results

Spirometric means of lung function and standard deviations were calculated for 3382 male and 3358 female participants. A complete list of population characteristics is available in Table 2, with differences noted by gender.

Calculated odds ratios

Group comparisons of lung function across housing characteristics suggested several statistically significant relationships. Figure 1 displays odds ratios (ORs) for FVC and FEV1. Figure 2 shows results for PEF and MMEF. "Ping-fang" housing (the equivalent of a single-family home) had a prevalence rate (PR) of 10% (Table 1) and was related to increased odds of FEV1 deficit (OR = 1.36, 95% CI: 1.03–1.80) when compared with "dan-yuan-lou-fang" housing (an apartment unit in a multi-story, multi-unit building). However, the "other" housing (PR = 3%) indicated greater FVC volumes (OR = 0.47, 95% CI: 0.26–0.83) compared with dan-yuan-lou-fang housing. Greater housing age was generally associated with better lung function. Residents of homes that were 5–10 years old (PR = 17%) yielded greater FVC volumes (OR = 0.75, 95% CI: 0.57–0.99) and FEV1 volumes (OR = 0.68, 95% CI: 0.51–0.93). Residents of homes that were 10–20 years old (PR = 47%) had greater FVC volumes (OR = 0.75, 95% CI: 0.60–0.94), FEV1 volumes (OR = 0.66, 95% CI: 0.51–0.84), and MMEF rates (OR = 0.78, 95% CI: 0.60–0.99). Finally, residents of homes >20 years old (PR = 23%) had greater FEV1 volumes (OR = 0.74, 95% CI: 0.56–0.97). All of these values reflecting home age were in comparison with houses <5 years old. Participants residing in dwellings within a floor area range of 15–25 m^2 had greater PEF rate (OR = 0.73, 95% CI: 0.57–0.93), whereas those within 35 m^2 or greater had higher MMEF rate (OR = 0.69, 95% CI: 0.49–0.98) when compared with homes with floor areas <25 m^2 (PR = 10%). No group differences were observed for story level or number of rooms.

Environmental conditions proximate to the dwelling contributed to low performance in spirometric measures. Participants residing in homes that were within 20 m of a major roadway (PR = 19%) were more likely to have increased odds of lung function deficit for all measures: FCV deficit (OR = 1.89; 95% CI: 1.55–2.29), FEV1 deficit (OR = 1.71; 95% CI: 1.37–2.13), PEF deficit (OR = 1.37; 95% CI: 1.06–1.76), and MMEF deficit (OR = 1.28; 95% CI: 1.03–1.59). Residents within a range of 20–100 m of a major roadway (PR = 35%) exhibited increased odds of FVC deficit (OR = 1.32; 95% CI: 1.11–1.57) compared with participants living more than 100 m from a major roadway (PR = 46%). Participants residing in homes within 100 m of a pollution source, such as a factory or smokestack (PR = 38%), were more likely to have increased odds of lung function deficit for all measures: FCV deficit (OR = 1.24; 95% CI: 1.06–1.44), FEV1 deficit (OR = 1.22; 95% CI: 1.03–1.46), PEF deficit (OR = 1.22; 95% CI: 1.03–1.46), and MMEF deficit (OR = 1.40; 95% CI: 1.19–1.66).

Other qualities of the home environment were also shown to have bearing on the odds of reduced lung function. Keeping of pets in the home (PR = 22%) was associated with increased odds of lung function deficit in residents for all measures: FCV deficit (OR = 1.29; 95% CI: 1.08–1.54), FEV1 deficit (OR = 1.46; 95% CI: 1.19–1.787), PEF deficit (OR = 1.38; 95% CI: 1.11–1.73), and MMEF deficit (OR = 1.38; 95% CI: 1.14–1.68). Similarly, home renovation within the previous two years (PR = 36%) was associated with increased odds of lung function deficit in residents for all measures: FCV deficit (OR = 1.86; 95% CI: 1.59–2.17), FEV1 deficit (OR = 2.90; 95% CI: 2.43–3.47), PEF deficit (OR = 1.51; 95% CI: 1.24–1.84), and MMEF deficit (OR = 1.94, 95% CI: 1.64–2.30). A pest sighting in the home during the previous 12 months (PR = 36%) was associated only with increased odds of PEF deficit (OR = 1.25; 95% CI: 1.02–1.53). Indoor coal use was notable only in the odds of reduced FEV1 (OR = 1.44; 95% CI: 1.07–1.93). Humidifier use was only associated with a lower MMEF rate (OR = 1.29; 95% CI: 1.06–1.58). The presence of mold or water damage in the home

Table 2. Characteristics of the study population of 6740 children in northern China.

	Male				Female				Total			
Characteristic	*n*	%	Mean	SD	*n*	%	Mean	SD	*n*	%	Mean	SD
City												
Shenyang	584	52.7	—	—	525	47.3	—	—	1109	16.5	—	—
Dalian	247	48.4	—	—	263	51.6	—	—	510	7.6	—	—
Fushun	1363	50.6	—	—	1332	49.4	—	—	2695	40.0	—	—
Anshan	333	51.3	—	—	316	48.7	—	—	649	9.6	—	—
Benxi	346	47.8	—	—	378	52.2	—	—	724	10.7	—	—
Dandong	387	49.2	—	—	399	50.8	—	—	786	11.7	—	—
Liaoyang	122	45.7	—	—	145	54.3	—	—	267	4.0	—	—
Child characteristic												
Age (years)	—	—	11.6	2.1	—	—	11.5	2.0	—	—	11.6	2.1
Height (cm)[a]	—	—	155.6	14.0	—	—	152.3	10.8	—	—	154	12.6
Weight (kg)[a]	—	—	51.2	17.3	—	—	45.7	13.2	—	—	48.4	15.6
Weekly exercise (h)[a]	—	—	7.9	7.6	—	—	7.4	7.9	—	—	7.6	7.7
Child breastfed[a]	2312	68.4	—	—	2439	72.6	—	—	4751	70.5	—	—
Family characteristic												
Parents as responders	3146	93.0	—	—	3145	93.7	—	—	6291	93.3	—	—
Family history of atopy	669	19.8	—	—	721	21.5	—	—	1390	20.6	—	—
Parent education level												
<High school	2101	62.1	—	—	2110	62.8	—	—	4211	62.5	—	—
Family annual income												
≤5000 RMB	375	11.1	—	—	383	11.4	—	—	758	11.2	—	—
5000–10 000 RMB	431	12.7	—	—	445	13.2	—	—	284	13.0	—	—
10 000–30 000 RMB	1197	35.4	—	—	1197	35.7	—	—	2394	35.5	—	—
30 000–100 000 RMB	1250	37.0	—	—	1187	35.4	—	—	2437	36.2	—	—
>100 000 RMB	129	3.8	—	—	146	4.3	—	—	275	4.1	—	—
Age of the home												
<5 years	408	12.1	—	—	441	13.1	—	—	849	12.6	—	—
5–10 years	548	16.2	—	—	577	17.2	—	—	1125	16.7	—	—
10–20 years	1629	48.2	—	—	1562	46.5	—	—	3191	47.3	—	—
≥20 years	797	23.5	—	—	778	23.2	—	—	1575	23.4	—	—
Home structure												
<3 stories	1059	31.3	—	—	1073	32.0	—	—	2132	31.6	—	—
3–7 stories	1942	57.4	—	—	1928	57.4	—	—	3870	57.4	—	—
>7 stories	381	11.3	—	—	357	10.6	—	—	738	11.0	—	—

(continued)

Table 2. (*concluded*)

Characteristic	Male				Female				Total			
	n	%	Mean	SD	*n*	%	Mean	SD	*n*	%	Mean	SD
Floor area of the home												
<15 m^2	608	18.0	—	—	661	19.7	—	—	1269	18.8	—	—
15–25 m^2	1651	48.8	—	—	1642	48.9	—	—	3293	48.9	—	—
25–35 m^2	780	23.1	—	—	726	21.6	—	—	1506	22.3	—	—
≥35 m^2	343	10.1	—	—	329	9.8	—	—	672	10.0	—	—
Number of rooms in the home												
<3	1316	38.9	—	—	1272	37.9	—	—	2588	38.4	—	—
≥3	2066	61.1	—	—	2086	62.1	—	—	4152	61.6	—	—
Distance from the home to traffic												
<20 m	630	18.6	—	—	625	18.6	—	—	1255	18.6	—	—
20–100 m	1191	35.2	—	—	1198	35.7	—	—	2389	35.5	—	—
>100 m	1561	46.2	—	—	1535	45.7	—	—	3096	45.9	—	—

Note: SD, standard deviation; RMB, Chinese Yuan.
[a]Significant differences between males and females indicated by the results of t or χ^2 tests, $p < 0.05$.

in the previous 12 months and the use of ventilation had no significant impact on the odds of abnormal spirometry measures.

ETS exposure during pregnancy was associated with increased odds of MMEF deficit (OR = 1.29; 95% CI: 1.06–1.58). ETS exposure in the first two years of life was associated with increased odds of FVC deficit (OR = 1.26; 95% CI: 1.05–1.51). Current ETS exposure was associated with increased odds of lung function deficit in residents for several measures: FCV deficit (OR = 1.51; 95% CI: 1.29–1.77), FEV1 deficit (OR = 1.48; 95% CI: 1.24–1.77), and MMEF deficit (OR = 1.33; 95% CI: 1.12–1.57).

Linear modeling of lung function

Several variables related to housing characteristics were significantly associated with altered lung function (Tables 3 and 4). As shown in Table 3, ping-fang housing was associated with deficits of FVC ($\beta = -112$; 95% CI: −159 to −64), FEV1 ($\beta = -85$; 95% CI: −127 to −43), and PEF ($\beta = -190$; 95% CI: −282 to −97), relative to dan-yuan-lou-fang housing. Residences with a floor area >15 m^2 were beneficial for lung function across all spirometry outcomes and all floor area categories, though no trend was noted with increasing floor area. Similarly, homes with more than three rooms were associated with better measures of FVC ($\beta = 40$; 95% CI: 11–69), when compared with homes with fewer rooms. The level of the residence being >7 stories was negatively associated with FEV1 ($\beta = -55$; 95% CI: −97 to −13). The age of the home exhibited no significant relationship to any of the four lung function indicators.

Environmental conditions in proximity to the dwelling were also associated with lower relative spirometric outcomes. Homes within <20 m of roadway traffic exhibited lower FEV1 ($\beta = -52$; 95% CI: −85 to −20), PEF ($\beta = -91$; 95% CI: −163 to −19), and MMEF ($\beta = -61$;

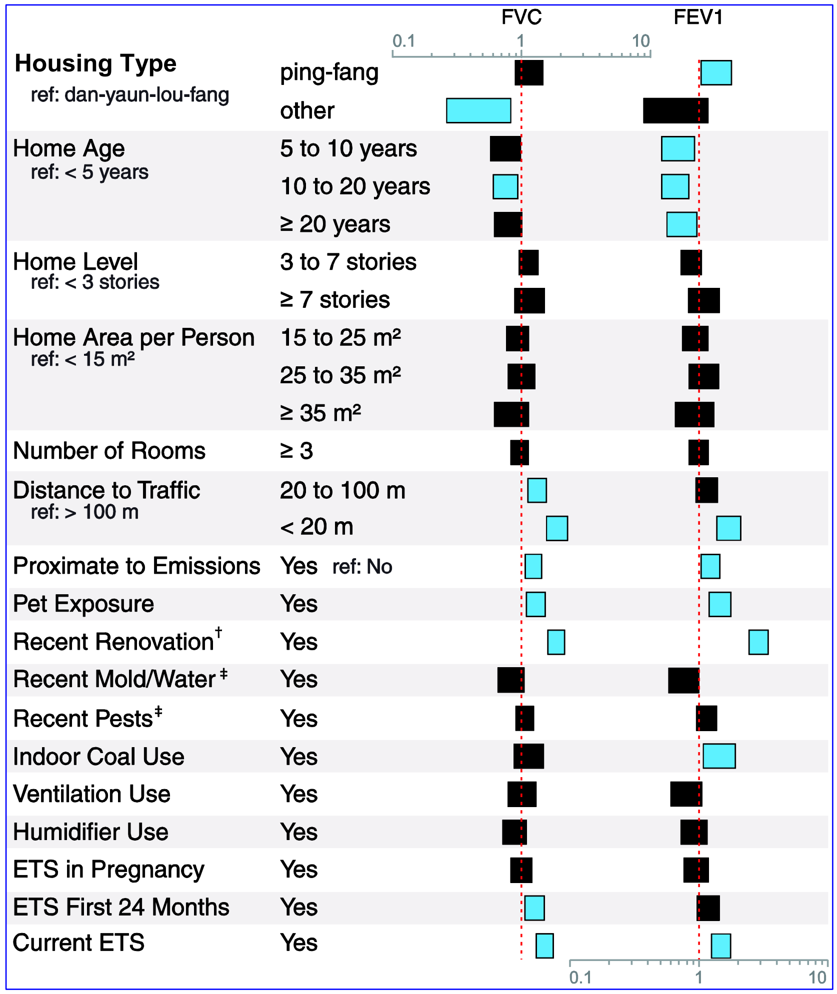

Fig. 1. The 95% CI of adjusted ORs (odds ratios)of forced vital capacity (FVC) and forced expiratory volume (FEV1) deficit by housing condition or quality among the study population of 6740 children in Northern China, log scale. ORs adjusted for age, gender, breast-feeding, parents' education, family income, home decorations, pet-keeping, current exposure to environmental tobacco smoke (ETS), family history of atopy, parents as responders, and districts. Blue indicates statistical significance. †Over the previous 24 months. ‡Over the previous 12 months.

95% CI: −115 to −8) values. Participants residing in homes within 100 m of a pollution source had reduced respiratory indicators for all measures.

Other qualities of the home environment of participants also had bearing on lung function measures (Table 4). The most influential variable was having a home renovation within the previous two years of assessment, which was associated with the greatest estimated deficit in lung function for FEV1 ($\beta = -241$; 95% CI: −265 to −216), PEF ($\beta = -262$; 95% CI: −317 to −207), and MMEF ($\beta = -240$; 95% CI: −279 to −198). The presence of pests in the home, indoor coal use, and ETS exposure were also associated with reduced respiratory indicators for all measures. In contrast, ventilation in the home was associated with slightly improved respiratory function measures for FVC ($\beta = 55$; 95% CI: 3–95), FEV1 ($\beta = 49$; 95% CI: 10–87), and MMEF ($\beta = 77$; 95% CI: 12–141).

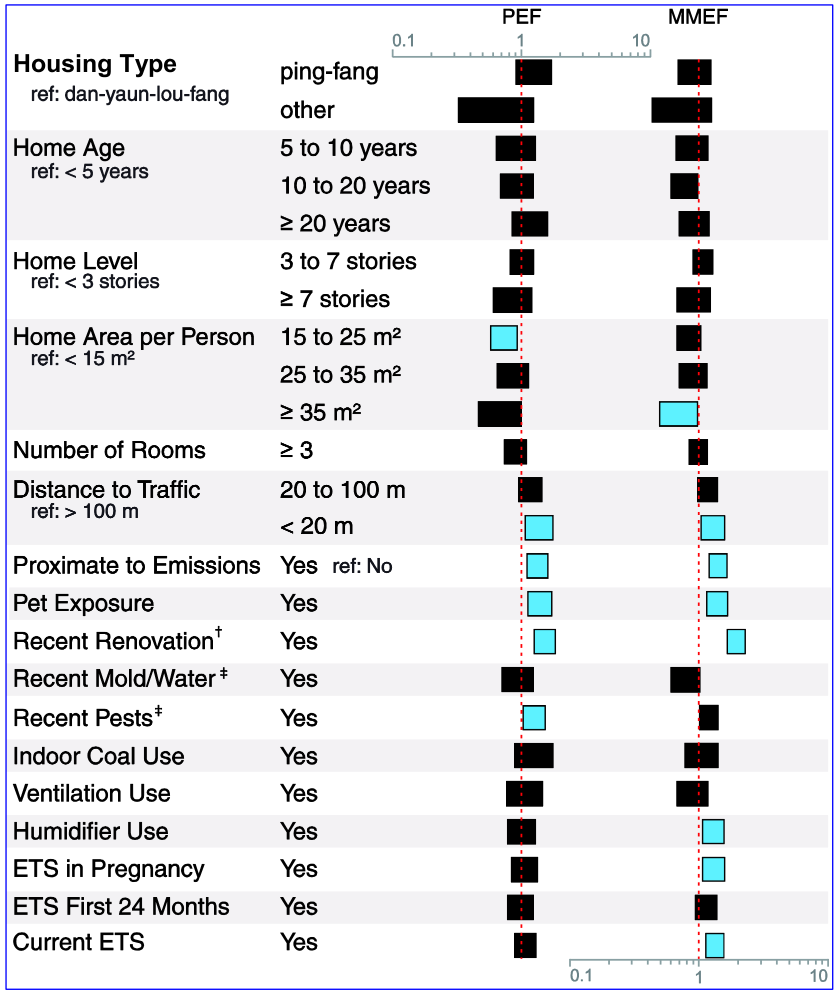

Fig. 2. The 95% CI of adjusted odds ratios (ORs) of peak expiratory flow (PEF) and maximal mid-expiratory flow (MMEF) deficit by housing condition or quality among the study population of 6740 children in Northern China, log scale. ORs adjusted for age, gender, breast-feeding, parents' education, family income, home decorations, pet-keeping, current exposure to environmental tobacco smoke (ETS), family history of atopy, parents as responders, and districts. Blue indicates statistical significance. †Over the previous 24 months. ‡Over the previous 12 months.

ETS exposure during pregnancy was associated with reduced FEV1 volume ($\beta = -31$; 95% CI: −61 to −1), and reduced MMEF rate ($\beta = -105$; 95% CI: −158 to −55).

Discussion

Few studies have investigated the range of adverse respiratory health effects associated with exposure to household sources of indoor air pollution in Chinese children. The primary strength of this study is the use of objective measures of lung function, building on the work previously performed as part of the SNEC study.

Several residential characteristics and environmental factors that were associated with an increased risk of diminished lung function were identified. Residents of ping-fang housing exhibited FEV1

Table 3. Estimate and 95% CI for lung function spirometric parameters and housing conditions among school children ($n = 6740$).[a]

	FVC (mL)		FEV1 (mL)		PEF (mL/min)		MMEF (mL/min)	
Feature	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Housing type (Ref: dan-yuan-lou-fang)								
Ping-fang	**−111.91**	**−159.45 to −64.37**	**−85.2**	**−127.21 to −43.19**	**−189.61**	**−281.79 to −97.43**	8.09	−60.65 to 76.83
Other	38.21	−41.55 to 117.97	46.97	−23.51 to 117.46	44.22	−110.44 to 198.88	52.24	−63.10 to 167.58
Age of the home (Ref: <5 years)								
5–10 years	−23.97	−74.16 to 26.21	20.06	−24.29 to 64.40	−32.01	−129.31 to 65.29	4.83	−67.66 to 77.30
10–20 years	−40.65	−83.39 to 2.09	29.75	−8.01 to 67.52	−52.98	−135.84 to 29.87	18.45	−43.27 to 80.17
≥20 years	−51.02	−98.24 to −3.81	21.86	−19.86 to 63.58	−62.81	−154.35 to 28.73	18.31	−49.88 to 86.50
Home structure (Ref: <3 stories)								
3–7 stories	24.51	−6.02 to 55.05	16.17	−10.81 to 43.13	29.71	−29.50 to 88.92	−10.66	−54.77 to 33.45
>7 stories	−33.56	−81.32 to 14.21	**−54.69**	**−96.87 to −12.51**	−43.97	−136.58 to 48.64	−45.37	−114.36 to 23.62
Floor area of the home (Ref: <15 m^2)								
15–25 m^2	**78.8**	**42.10–115.50**	**60.19**	**27.73–92.65**	**122.45**	**51.24–193.66**	**85.28**	**32.21–138.35**
25–35 m^2	**118.48**	**75.10–161.86**	**78.03**	**39.66–116.39**	**172.85**	**88.68–257.01**	**82.36**	**19.63–145.10**
≥35 m^2	**122.9**	**68.37–177.43**	**78.54**	**30.31–126.76**	**183.02**	**77.22–288.82**	**79.99**	**1.14–158.85**
Number of rooms in the home (Ref: <3)								
≥3	**40.12**	**11.40–68.83**	24.92	−0.45 to 50.30	51.12	−4.55 to 106.79	11.08	−30.40 to 52.55
Distance from the home to traffic (Ref: >100 m)								
20–100 m	−15.22	−45.30 to 14.87	−16.48	−43.08 to 10.12	−37.16	−95.53 to 21.21	**−70.18**	**−113.64 to −26.72**
<20 m	−83.86	−120.84 to 46.87	**−52.29**	**−84.99 to −19.59**	**−91.02**	**−162.78 to −19.26**	**−61.44**	**−114.87 to −8.01**
Pollution source near the home (Ref: No)								
Yes	**−74.56**	**−102.33 to −46.79**	**−71.33**	**−95.85 to −46.81**	**−203.28**	**−256.99 to −149.58**	**−158.05**	**−198.04 to −118.07**

Note: Numbers in bold indicate a p-value <0.05. FVC, forced vital capacity; FEV1, forced expiratory volume; PEF, peak expiratory flow; MMEF, maximal mid-expiratory flow; Ref, reference group for comparison.
[a]Adjusted for age, gender, body mass index, breast-feeding, parents' education, family income, home decorations, pet-keeping, current exposure to ETS, family history of atopy, parents as responders, and districts.

deficit compared with those living in multi-family structures and dormitories. They also exhibited reduced lung function for FVC, FEV1, and PEF in the linear model. This is contrary to the findings of Zhang et al. (2013) that children in Wuhan, China, residing in apartment buildings had greater odds of being diagnosed with allergic rhinitis (OR = 1.53; 95% CI: 1.16–2.00) than those residing in single-family housing. In the present study, residents living in ping-fang housing are usually poor and the indoor pollution was much heavier than that in the apartments. For example, 73.1% of subjects living in ping-fang housing reported the use of coal for cooking or heating, while only 2.5% of subjects living in apartments reported this use. In addition, the education level and family annual income were lower in the residents of ping-fang housing than those of apartment housing (parental education < high school: 78% vs. 32%; family annual income <10 000 RMB: 37% vs. 22%). Thus, living in ping-fang housing may represent the social economic characteristics of a poverty-stricken population and may hold higher vulnerability for disease risk when exposed to environmental factors.

Table 4. Estimate and 95% CI for lung function spirometric parameters and home environmental factors among school children ($n = 6740$).[a]

	FVC (mL)		FEV1 (mL)		PEF (mL/min)		MMEF (mL/min)	
Feature	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Exposure to pets (Ref: No)								
Yes	−7.99	−41.65 to 25.66	−13.41	−42.40 to 15.57	−45.42	−110.35 to 19.51	−23.04	−71.29 to 25.21
Home renovation in the past 2 years (Ref: No)								
Yes	**−84.01**	**−112.39 to −55.63**	**−240.73**	**−265.17 to −216.28**	**−262.07**	**−316.84 to −207.31**	**−238.28**	**−278.97 to −197.58**
Mold in the past 12 months (Ref: No)								
Yes	−0.80	−41.11 to 39.51	9.23	−25.49 to 43.94	31.46	−46.30 to 109.23	47.31	−10.48 to 105.10
Pests in the past 12 months (Ref: No)								
Yes	**−55.5**	**−84.39 to −26.62**	**−50.24**	**−75.12 to −25.36**	**−122.99**	**−178.73 to −67.27**	**−63.08**	**−104.49 to −21.67**
Indoor coal use (Ref: No)								
Yes	**−111.34**	**−161.7 to −60.99**	**−122.27**	**−165.63 to −78.91**	**−247.09**	**−344.21 to −149.96**	−49.99	−122.17 to 22.18
Ventilation device use (Ref: No)								
Yes	**50.27**	**2.57–94.97**	**48.82**	**10.32–87.33**	49.72	−36.53 to 135.96	**76.51**	**12.42–140.60**
Humidifier device use (Ref: No)								
Yes	1.39	−35.61 to 38.39	−7.94	−39.80 to 23.93	−10.65	−82.04 to 60.73	−33.73	−86.77 to 19.32
ETS exposure during pregnancy (Ref: No)								
Yes	−12.93	−47.51 to 21.65	**−31.04**	**−60.83 to −1.26**	−44.09	−110.81 to 22.63	**−104.93**	**−157.52 to −55.35**
ETS exposure in the first 2 years of life (Ref: No)								
Yes	−27.64	−61.33 to 6.04	**−36.45**	**−65.47 to −7.44**	−37.58	−102.58 to 27.42	**−72.82**	**−121.15 to −24.49**
Current ETS exposure (Ref: No)								
Yes	**−70.19**	**−97.25 to −43.12**	**−65.68**	**−88.99 to −42.37**	−37.41	−89.73 to 14.91	**−67.33**	**−106.23 to −28.43**

Note: Numbers in bold indicate a p-value <0.05. FVC, forced vital capacity; FEV1, forced expiratory volume; PEF, peak expiratory flow; MMEF, maximal mid-expiratory flow; ETS, enhanced tobacco smoke; Ref, reference group for comparison.
[a]Adjusted for age, gender, body mass index, breast-feeding, parents' education, family income, home decorations, pet-keeping, current exposure to ETS, family history of atopy, parents as responders, and districts.

Previous work by the authors failed to find any significant relationships between housing type and reported respiratory symptoms consistent with asthma (Dong et al. 2008). Langer and Bekö (2013) found higher concentrations of VOCs and formaldehyde in Swedish single-family homes compared with apartment buildings and highlighted the importance of air exchange in residences. This was not considered in this research and could play a role in our observations. Though this study examined the effect of ventilation associated with cooking on respiratory function, it did not address ventilatory air exchange. No significant relationships were observed for ventilation in the logistic model and only small, yet significant, effects were obtained from the linear model.

Taken together, the findings from the age of the residence and recent home renovations bolster previous findings related to respiratory outcomes and new construction in this region of China. In prior work, the authors have speculated that this finding may be relates to self-reported allergic rhinitis in adult women (Dong et al. 2013) and children (Dong et al. 2008). However, the consistent findings of the odds of spirometric deficit and the observed, large effects in the linear model of children in homes recently renovated increases the concern of the impact of indoor air contaminants on children. This suggests that builders and renovators may be choosing materials and construction methods that may be hazardous to the respiratory health of children.

Off-gassing of VOCs is a potential source of respiratory irritants and is dependent on factors related to the manufacturing and composition of building materials, paint and coatings, and furniture. Raw et al. (2004) found increased levels of VOCs and formaldehyde in newer homes and in homes that had undergone recent painting. The work of Jaakkola et al. (2004, 2006) has provided evidence of both ongoing off-gassing of VOCs from paint following renovation and epidemiological evidence to support respiratory effects in adults following renovation. Dong et al. (2014) also found that the students living in newly renovated residences had higher rates of rhinitis, cough, and shortness of breath compared with controls. However, these studies did not evaluate the impact of renovations on lung function and found no significant relationships.

A recent review by Chen et al. (2010) highlighted the inconsistent findings regarding an association between the keeping of dogs and cats and asthma or allergic diseases. The authors concluded that exposure to pets does not have an impact on development of asthma and wheezing (Chen et al. 2010). They also determined that early exposure to cats may cause sensitization to cat allergen, but early exposure to dogs may cause a protective effect (Chen et al. 2010). Our findings of respiratory deficits in children living in homes with pets provide quantitative evidence of the effects of pet-keeping on lung function, though not without some curious inconsistency. The odds of respiratory deficit were significant for all measures of spirometric performance, but the linear modeling of effect indicated no significant deficits associated with pets. That being the case, there are still unresolved mechanisms with respect to respiratory effect and the nature and frequency in which pets interact with people as well as how pets are domiciled (i.e., inside or outside the home). This study was not designed to specifically answer these questions, but serves as a potential avenue for future studies. It should also be noted that this study included poultry in the definition of pet-keeping, which may not be typical in other parts of the world.

The presence of mold or water damage in the home within a year had no statistically significant impact on the odds of respiratory deficit and no significant effects on spirometric performance in the linear model. Some estimates, though not significant, indicated a protective effect with mold or water in the home. However, the exposure to mold was based on parental self-reporting and not all mold and water issues are readily visible. It is known that mold proliferation is dependent on the growth medium and the presence of moisture (Van Loo et al. 2004) and that the presence of mold is linked to respiratory health outcomes (Mendell and Kumagai 2017). However, many questions remain in our understanding of the interaction between fungal organisms, fungal metabolic products, and environments (Nevalainen et al. 2015). Related to this potential source of respiratory irritation is the use of a humidifier, which has previously been found to have an impact on respiratory outcomes. In this study, the use of a humidifier was only associated with reduced MMEF rate.

The presence of pests in the home in the previous year was found to be associated with greater odds of PEF deficit and significant deficits to lung function were observed in all four spirometric measures. The role of pests in asthma and allergy has been noted previously and was recently summarized by Sheehan et al. (2010). Our findings are largely supported by the Sheehan review, but they suggest that future studies should examine the role of pests on objective lung function. They also suggest that intervention studies examining the effect of pest management should consider spirometric performance to assess the effect on pest mitigation in addition to the reporting of asthma symptoms.

Proximity to pollution sources, both from roadway traffic and point sources, was associated with reduced lung function. The Children's Health Study in Southern California (Gauderman et al. 2004, 2007), the Oslo Birth Cohort (Oftedal et al. 2008), and a recent cohort study by Schultz et al. (2012) represent strong evidence that exposure to pollution from traffic has adverse effects on children's lung function development, though Schultz et al. (2012) concluded that the effect was greatest in the first year of life. Our findings are consistent with these studies and add further evidence to this relationship. Children who lived within 20 m of traffic, when compared with children who lived more than 100 m from traffic, experienced greater odds of respiratory deficit for all four measures of lung function and significant effects for FEV1, PEF, and MMEF in the linear model.

Several studies have examined the effects of ETS on child respiratory health outcomes at different stages of growth. Some have associated fetal exposure via maternal smoking with respiratory symptoms (Lannerö et al. 2006; Håberg et al. 2007). Others have demonstrated effects due to postnatal exposure to ETS (Öberg et al. 2011; Burke et al. 2012). Our findings indicated that current exposure to ETS exhibited the strongest impact on children who were exposed at the time of the study. The odds of respiratory deficits in FVC, FEV1, and MMEF were significant for current ETS, but only a deficit in MMEF was significant for ETS exposure during pregnancy. Similarly, significant odds of respiratory deficit are noted for FVC, FEV1, and MMEF for current ETS exposure, and detrimental effects are indicated for FEV1 and MMEF in the linear model. Exposure to ETS in the first two years of life did not indicate odds of lung function deficit but exhibited effects in the linear model for FEV1 and MMEF.

Although the data were thoroughly detailed and a large sample ($n = 6740$) was utilized, our study contained a few limitations. First, the cross-sectional nature of the study cannot establish temporal effects between housing characteristics or environmental exposures and the measured spirometric outcomes. Second, there may have been confounding variables not accounted for in this study that could have played a role in lung function deficit such as body composition (Scott et al. 2012) and dietary factors (Veeranki et al. 2015). Third, although new and renovated homes had higher odds of lung function deficit, no measures of indoor air quality were taken that could implicate particular exposure sources in lung function deficit.

Conclusion

Given the size of the study population and the quantitative measures of lung function, this work provides further evidence regarding household and environmental factors that contribute to lung function deficit. Future work with this population should attempt to better explain the effects of new building practices on residents and resolve the underlying exposure mechanisms—either by removal or mitigation—to reduce the impact of new materials and building practices on child respiratory health. Furthermore, these findings suggest that control of indoor air pollutants and initiation of efforts to protect children from heavy indoor air pollution exposure in China should be a priority.

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Author contributions

ZQ and G-HD conceived and designed the study. L-WH, B-YY, and G-HD performed the experiments/collected the data. BE, L-WH, and B-YY analyzed and interpreted the data. L-WH, B-YY, KAM, CG, MV, and G-HD contributed resources. BE, KAM, CG, MV, and ZQ drafted or revised the manuscript.

Competing interests

The authors have declared that no competing interests exist.

Data accessibility statement

All relevant data are within the paper and available from the authors upon request.

Supplementary material

The following Supplementary Material is available with the article through the journal website at doi:10.1139/facets-2017-0036.

Supplementary Material 1

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