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Association of building characteristics, residential heating and ventilation with asthmatic symptoms of preschool children in Shanghai: A cross-sectional study

Wei Liu¹, Chen Huang¹, Yu Hu¹, Zhijun Zou¹,
Zhuohui Zhao² and Jan Sundell³

Abstract

A China, Children, Homes, Health (CCHH) study was conducted in Shanghai to investigate the associations between residential characteristics and childhood asthma, wheeze and dry cough of 4- to 6-year-old children. In the present study, 13,335 children participated in the questionnaire survey, and the questionnaires were completed by children's parents with a response rate of 85.3%. Multiple logistic regression analysis was the main method for analyses. Using wood as fuel for cooking was shown to have a strong positive association with asthma (adjusted odds ratio, 95% confidence interval: 2.84, 1.24–6.54). Existence of a highway within 200 m of the residence could have a positive association with wheeze ever (1.20, 1.02–1.41) and dry cough (1.22, 1.02–1.40). Children having suffered wheeze symptom ever was negatively associated with the use of fume exhaust ventilator in the kitchen (0.85, 0.73–0.99) and exhaust fan in the bathroom (0.86, 0.78–0.95) but positively associated with the use of home air purifier (1.22, 1.05–1.41). The results indicated that the residential characteristics such as surrounding environment and household equipments could have notable association with children's health in Shanghai. Using clean fuel for home cooking, living far away from a highway or increasing home ventilation could possibly reduce the children's risk of suffering asthmatic symptoms.

Keywords

Asthma, Homes, Preschool children, Shanghai, Wheeze, Ventilation

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Introduction

Along with the rapid urbanization and modernization in China, more and more residences are being reconstructed from low-rise buildings or single-storey housings to high-rise multi-storey apartment buildings with high population density. Many household equipments (e.g. air conditioners) and man-made materials and furnishing are commonly used in the residences,¹ and these could possibly have an effect on indoor environmental pollution.² At the same time, the prevalence of asthmatic symptoms has been increasing significantly in China and has been reported to have a strong

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association with certain environmental exposures.³ In Shanghai, the prevalence of asthma among 4- to 6-year-old children was greatly increased from 2.30% in 1990⁴ to 10.3% in 2011.^{5,6} Numerous studies have revealed significant associations between childhood asthmatic symptoms and residential environmental factors, such as home dampness,⁷⁻⁹ building characteristics,¹⁰⁻¹⁸ household ventilation,¹⁹ traffic density and ambient air pollution²⁰⁻²² and types of indoor air pollutants.^{23,24} However, most of these relative studies were carried out in the developed countries or regions. Few similar studies have been conducted in China. Shanghai, which is the largest developed city in China, is still being rapidly developed in many urban areas. People's lifestyles and home characteristics could vary greatly with different socio-economic status in different areas. The purpose of this study was to investigate the relative factors that can be associated with the rapid increasing prevalence of asthmatic symptoms among preschool children in Shanghai. Based on a large-scale cross-sectional China, Children, Homes, Health (CCHH) study in Shanghai, the present study has the following objectives:

1. to investigate the selected building and residential characteristics (e.g. age, area, location, type, ownership, ambient environment) of those residences with 4- to 6-year-old preschool children;
2. to analyse the usage of residential heating, ventilation and air-conditioning (HVAC) system and some other modern air handling equipments in different districts, and to study correlations between the usage of these equipments;
3. to investigate association between childhood asthmatic symptoms and building or residential characteristics, the usage of home HVAC equipments, air humidifier and cleaner.

Materials and methods

Questionnaire

During the period from April 2011 to April 2012, a cross-sectional study (CCHH-Phase one in Shanghai) about children's asthma, allergic symptoms and indoor environment was conducted in three urban districts (Jing-an, Zhabei and Hongkou) and two suburban districts (Baoshan and Fengxian) of Shanghai. Figure 1 shows the locations of these studied districts. In total, 72 kindergartens were chosen randomly in those districts, about 15 kindergarten in each district. A total of 17,898 questionnaires were distributed to the children's parents or guardians at the teachers-parents meetings in the kindergartens or by post to the teachers who distributed the questionnaires with handout explanation and guidance. The questions about children's symptoms were the same as the standard questionnaires given in the International Study of Asthma and Allergies in Childhood (ISAAC).²⁵ The questionnaires for those asthmatic symptoms in this study are as follows:

1. Wheeze, ever: Has your child ever had wheeze or whistling in the chest at any time in the past? Yes [prior to 1 year of age or 1-2 years of age or 3-4 years of age or more than 4 years of age] versus No;
2. Wheeze, during last 12 months: Has your child had wheeze or whistling in the chest in the last 12 months? Yes [when having a cold or during exercise or when playing or being outdoors or when laughing or crying or in contact with furred animals] versus No;
3. Dry cough, during last 12 months: In the last 12 months, has your child had a dry cough at night for more than two weeks, apart from a cough associated with a cold or chest infection? Yes versus No;

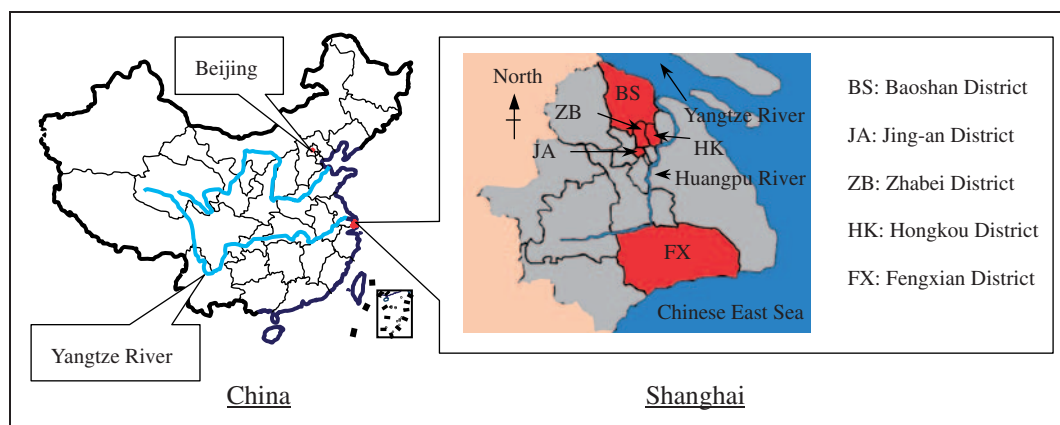


Figure 1. The location of surveyed districts in Shanghai.

4. Doctor-diagnosed asthma: Has your child ever been diagnosed with asthma by a doctor? Yes versus No.

The questions about family background, lifestyle, building characteristics and indoor environmental factors were similar to the Dampness in Buildings and Health (DBH) study in Sweden,²⁶ the ALLHOME study in Bulgaria²⁷ and the CCHH study in other Chinese cities.³ The questionnaire was slightly modified according to the building characteristics and life culture in Shanghai. The main questions that were analysed in this study have been discussed in a previous study by Zhang et al.³

Statistical analysis

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS, version 17.0; SPSS Ltd., Chicago, IL, USA). Pearson's Chi-square (χ^2) test was used to determine the differences between groups. Gamma correlation analysis, which is similar to the Pearson's correlation analysis, was used to investigate correlations between home mechanical ventilation, type of heating and different air handling equipments because the variables are dichotomous (Yes vs. No). Logistic regression analysis was applied to investigate crude associations between building characteristics, the use of HVAC and children's symptoms. Multiple logistic regression analysis was used to adjust the potential confounders, which included age (≤ 4 years old vs. > 4 years old), gender (male vs. female), family history of asthma or allergies (Yes vs. No), breastfeeding (≤ 6 months vs. > 6 months), location of the kindergarten (urban area vs. suburb), home dampness-related exposures (Yes vs. No), pet-keeping at child's birth (Yes vs. No) and current parental smoking (Yes vs. No). The multivariate models were constructed by one health outcome (as dependent variable, Yes vs. No), one target factor (as independent variable, Yes vs. No) and all of the confounders as mentioned above (as covariant). Associations would be indicated by crude odds ratio (OR) and adjusted odds ratio (AOR) with 95% confidence interval (CI). The significance in statistical analyses would be indicated by p value < 0.05 .

Results

Demographic data

The study received 15,266 valid completed questionnaires returned from the parents of the children aged 1–8 years. The response rate was 85.3%. However, 300 questionnaires that did not fill out the age were returned. The number of the questionnaires

from children aged 1–2 years ($n=33$), 3 years ($n=749$), 7 years ($n=800$) and 8 years ($n=49$) were much smaller than the returned questionnaires from children aged 4 years ($n=5561$), 5 years ($n=4399$) and 6 years ($n=3375$). Thus, 13,335 returned questionnaires from 4- to 6-year-old children were selected for further analyses. Herein 9114 (70.4%), 3076 (23.8%) and 748 (5.8%) of questionnaires were answered by the mother, father and other appropriate guardian, respectively. The proportions of boys and girls were 50.8% and 49.2%, respectively. The proportions of children from urban and suburban kindergartens were 56.8% and 43.2%, respectively. The number of children from different districts and their details regarding their housings were included in the statistical analyses and these are given in Table 1.

Building characteristics and usage of household HVAC

Table 1 shows the main building characteristics and the total usage of HVAC of the 13,335 households and shows the proportions of these dwelling situated in different districts of Shanghai. The residences of these households were characterized by types, sizes, built age, surrounding environments and ownership. Most of the characteristics of their dwellings were significantly different among different urban or suburban districts, or between urban districts and suburban districts. More than half of these dwellings were owned by residents.

The residences included in the study are mainly multi-storey apartment dwellings (MSAD) and detached housings for single families (DHSF). Urban districts have more MSAD but less detached housings than suburban districts. Only 1.2% of the studied dwellings are semi-detached dwelling (SDD). In urban districts, the proportions of residents in three different areas are almost equal, while in suburban districts, the largest proportion of dwellings is 61–100 m².

The majority of dwellings were built in 1991–2005 periods. A number of residences are surrounded by highways and commercial districts within 200 m distances of the dwellings. More than one-fifth of residences are surrounded with commercial areas. Furthermore, home heating are mainly by the use of air conditioner and electric room heater. Other heating methods are seldom used. The proportion of the residences without heating in suburb is significantly higher than in urban areas. In these surveyed suburban districts, the residences in Fengxian District have less heating than in Baoshan District. Several dwellings in Fengxian and Baoshan still do not use any form of heating. Natural gas, electricity and coal are the main fuel generally being used for cooking. Several residences use more than two fuels for cooking.

Table 1. The main building characteristics and the usage rates of HVAC in different districts of Shanghai.

Percentage (%)	Total (N, %)	Urban districts				Suburban districts				p^c
		Total	Zhabei	Jing-an	Hongkou	p^a	Total	Fengxian	Baoshan	
Sample size (N)	13,335, 100	7576	3071	2598	1907		5759	3306	2453	
Type of the residence										
DHSF	2913, 22.4	21.1	24.9	15.7	22.3	<0.001	24.3	28.3	18.8	<0.001
SDD	151, 1.2	0.7	0.6	1.1	0.6	0.068	1.7	2.3	0.9	<0.001
MSAD	8886, 68.5	70.5	66.8	75.8	69.1	<0.001	65.7	59.5	74.1	<0.001
Others	1031, 7.9	7.7	7.7	7.4	8.0	0.780	8.3	9.9	6.2	<0.001
Size of the residence (m ²)										
≤60	4563, 35.1	34.7	39.4	33.3	29.2	<0.001	35.5	30.7	42.1	<0.001
61–100	4597, 35.3	32.4	36.7	23.6	37.2	<0.001	39.2	42.5	34.7	<0.001
≥101	3852, 29.6	32.9	23.9	43.1	33.5	<0.001	25.3	26.8	23.2	0.002
Built period of the residence										
Before 1980	1287, 10.1	14.0	14.0	14.5	13.6	0.703	4.8	3.6	6.4	<0.001
1980–1990	1777, 13.9	14.7	19.1	9.6	14.9	<0.001	12.9	10.9	15.5	<0.001
1991–2000	4138, 32.4	31.3	32.2	31.6	29.4	0.112	34.0	34.9	32.8	0.113
2001–2005	3673, 28.8	30.9	26.2	34.7	33.0	<0.001	26.0	27.1	24.6	0.040
2006–present	1881, 14.8	9.1	8.5	9.6	9.2	0.370	22.3	23.5	20.7	0.013
Surrounding environment of the residence (within 200 m)										
High way	4833, 40.6	39.4	43.1	31.9	43.4	<0.001	42.2	41.3	43.5	0.108
River or lake	1372, 11.5	7.0	5.0	9.9	6.1	<0.001	17.4	18.5	15.8	0.011
Commercial area	3535, 29.7	36.0	29.8	50.5	26.5	<0.001	21.7	19.8	24.4	<0.001
Industrial area	825, 6.9	1.0	1.3	0.7	1.0	0.177	14.5	13.7	15.7	0.046
Ownership of the residence										
Owner	8224, 63.2	65.9	61.9	69.5	67.6	<0.001	59.5	53.2	68.1	<0.001
Tenant	4795, 36.8	34.1	38.1	30.5	32.4	<0.001	40.5	46.8	31.9	<0.001
Type of heating										
Air conditioner	10,290, 77.9	84.5	85.4	82.2	86.0	<0.001	69.2	64.6	75.3	<0.001
Electric heater	2728, 20.6	21.6	21.1	23.2	20.4	0.047	19.3	16.2	23.6	<0.001
Floor heating	175, 1.3	2.0	0.6	4.0	1.4	<0.001	0.5	0.5	0.5	0.849
Others	342, 2.6	1.9	2.0	2.0	1.7	0.818	3.5	4.7	1.9	<0.001
More than two methods	1874, 14.2	16.1	15.6	17.5	15.0	0.047	11.7	9.5	14.5	<0.001
No heating	1613, 12.2	6.5	6.7	6.5	6.2	0.741	19.7	24.0	13.9	<0.001

(continued)

(continued)

Table 1. Continued.

Percentage (%)	Total (N, %)	Urban districts				Suburban districts				<i>p</i> ^c	
		Total	Zhabei	Jing-an	Hongkou	<i>p</i> ^a	Total	Fengxian	Baoshan		<i>p</i> ^b
Fuel being used for cooking											
Coal	1558, 11.8	15.6	14.2	16.8	16.0	0.022	6.9	6.3	7.6	0.071	<0.001
Wood	83, 0.6	0.3	0.3	0.3	0.4	0.839	1.0	1.5	0.4	<0.001	<0.001
Natural gas	8977, 68.0	66.6	67.8	65.8	65.8	0.202	69.9	64.4	77.4	<0.001	<0.001
Electricity	3653, 27.7	25.1	26.8	23.2	25.1	0.009	31.1	36.3	24.1	<0.001	<0.001
Others	711, 5.4	4.2	3.0	5.1	4.8	<0.001	7.0	9.2	4.0	<0.001	<0.001
More than two fuels	1777, 13.5	11.8	12.2	11.3	12.0	0.545	15.6	17.3	13.5	<0.001	<0.001
Exhaust fan in the bathroom											
Yes	10,256, 78.7	82.2	80.6	84.4	81.6	0.001	74.1	68.6	81.5	<0.001	<0.001
No	2777, 21.3	17.8	19.4	15.6	18.4	0.001	25.9	31.4	18.5	<0.001	<0.001
Exhaust equipments in the kitchen											
Fume exhaust ventilator	11,314, 86.1	88.2	87.5	88.5	88.8	0.340	83.4	78.4	90.2	<0.001	<0.001
Exhaust fan	2090, 15.9	17.0	16.1	18.8	16.1	0.012	14.4	14.6	14.1	0.629	<0.001
None	1147, 8.7	7.3	7.2	7.6	6.9	0.636	10.7	14.5	5.6	<0.001	<0.001
Have the equipments for indoor air quality, stated below, in the residence											
Air conditioner	11,990, 96.1	96.3	96.8	95.5	96.6	0.038	95.8	94.6	97.3	<0.001	0.151
Air humidifier	2123, 17.0	20.2	17.8	23.7	19.3	<0.001	12.6	8.8	17.4	<0.001	<0.001
Air purifier	993, 8.0	10.5	7.5	15.6	8.2	<0.001	4.5	2.6	6.8	<0.001	<0.001
Air ionizer	181, 1.5	1.8	1.5	2.0	2.1	0.258	0.9	0.6	1.3	0.006	<0.001

DHSF: detached housings for single families; SDD: semi-detached dwelling; MSAD: multi-storey apartment dwellings.

^aChi-square test for the difference between different urban districts (2 × 3 times tables, classification in row is Yes vs. No).^bChi-square test for the difference between different suburban districts (2 × 2 times tables, classification in row is Yes vs. No).^cChi-square test for the difference between urban (total) and suburban districts (total) (2 × 2 times tables, classification in row is Yes vs. No).

Urban residences would use more coal, but less natural gas and electricity, than suburban residences.

Most of the residences studied have fume exhaust ventilator in the kitchen and exhaust fan in the bathroom. Besides, some residences have exhaust fan in the kitchen. Urban usages of these exhaust equipments are higher than suburban districts. Among those residences studied, almost all of them have air conditioners, while the usages of air humidifier, air purifier and air ionizer are relatively small. Herein most of the studied residences which use air humidifier (94.3%) and air purifier (85.9%) simultaneously have home air conditioner (data are not shown in the tables). The usages of these equipments for maintenance of indoor air quality in urban districts are higher than in suburban districts.

Table 2 shows the correlations among different mechanical ventilation, heating and different air handling equipments. Most of the correlations are statistically significant ($p < 0.05$). Fume exhaust ventilator in kitchen has a significantly negative correlation with the use of an exhaust fan in the kitchen but has a positive correlation with the use of an exhaust fan in the bathroom. There are significantly negative correlations between different types of heating. Among different air handling devices, air conditioner has a negative correlation with other air handling devices, whereas there are significantly positive correlations between air humidifier, air purifier and air ionizer. Moreover, there are obvious positive correlations among different mechanical ventilation, different types of heating and different air handling devices. Especially, fume exhaust ventilator and floor heating are notably correlated with different air handling devices.

Prevalence of asthma and asthmatic symptoms

Table 3 shows the overall prevalence of asthma and asthmatic symptoms in different districts of Shanghai, among the studied families. Generally, the prevalence in urban districts was higher than in suburban districts. The prevalence of asthma among children in Hongkou District was the highest and twofold higher than among children in Fengxian District. Among those urban districts, Jing-an District has the lowest prevalence of asthma but was reported to have the highest prevalence of asthmatic symptoms, while Zhabei District had the highest prevalence of these symptoms. During the last 12 months prior to the study (April 2011–April 2012), most wheeze occurred when children had a cold (19.7% of total 21.7%, data are not shown in the table).

Associations

Table 4 shows the prevalence of asthma and asthmatic symptoms within different situations. The prevalence of

Table 2. The correlations among different home mechanical ventilation, type of heating and different air-handled devices.

	Coefficient of correlation, G (p value ^a)									
	Type of ventilation			Type of heating			Air handled devices			
	FEV	Exhaust fan (bathroom)	Air conditioner	Electric heater	Floor heating	Air conditioner	Air humidifier	Air purifier	Air ionizer	
Type of ventilation										
Exhaust fan in kitchen	-0.605 (<0.001)	0.053 (0.070)	0.034 (0.240)	0.099 (0.001)	0.384 (<0.001)	-0.142 (0.026)	0.122 (<0.001)	0.123 (0.007)	0.281 (0.005)	
Fume exhaust ventilator		0.827 (<0.001)	0.577 (<0.001)	-0.096 (0.002)	0.370 (0.001)	0.548 (<0.001)	0.539 (<0.001)	0.509 (<0.001)	0.084 (0.464)	
Exhaust fan in bathroom			0.441 (<0.001)	-0.080 (0.003)	0.575 (<0.001)	0.286 (<0.001)	0.443 (0.031)	0.435 (<0.001)	0.472 (<0.001)	
Type of heating										
Air conditioner				-0.431 (<0.001)	-0.771 (<0.001)	0.636 (<0.001)	0.309 (<0.001)	0.149 (<0.001)	0.122 (0.196)	
Electric heater					-0.624 (<0.001)	0.000 (0.992)	0.161 (<0.001)	0.078 (0.059)	0.083 (0.369)	
Floor heating						-0.448 (0.014)	0.393 (<0.001)	0.634 (<0.001)	0.595 (0.026)	
Air-handled devices										
Air conditioner							-0.254 (<0.001)	-0.683 (<0.001)	-0.665 (<0.001)	
Air humidifier								0.613 (<0.001)	0.722 (<0.001)	
Air purifier									0.827 (<0.001)	

FEV: Fume exhaust ventilator.

^a p values in significant test (two-tailed) are corresponded in the parentheses. All of significant coefficients ($p < 0.05$) are bold.

Table 3. The prevalence of asthma and asthmatic symptoms in different districts of Shanghai.

Percentage (%)	Total (N, %)	Urban district					Suburban district				
		Total	Zhabei	Jing-an	Hongkou	p^a	Total	Fengxian	Baoshan	p^b	p^c
Asthma, doctor-diagnosed	1342, 10.3	11.9	11.9	10.1	14.6	<0.001	8.2	6.5	10.6	<0.001	<0.001
Wheeze, ever	3722, 28.3	28.2	24.1	31.4	30.6	<0.001	28.5	27.5	29.7	0.070	0.796
Wheeze, last 12 months	2858, 21.7	21.1	17.2	24.9	22.2	<0.001	22.5	22.7	22.2	0.685	0.058
Dry cough, last 12 months	2569, 19.5	20.0	15.3	25.7	19.7	<0.001	18.8	17.3	20.8	0.001	0.098

^aChi-square test for the difference between different urban districts (2*3 times tables, classification in row is Yes vs. No).

^bChi-square test for the difference between different suburban districts (2*2 times tables, classification in row is Yes vs. No).

^cChi-square test for the difference between urban and suburban districts (total) (2*2 times tables, classification in row is Yes vs. No).

asthma and dry cough were obviously different among those families studied, living in dwellings of different types and sizes, while the prevalence of wheeze was not obviously different among those families living in such types and sizes of dwellings. Those children—living within 200 metres close to the highway, have significantly higher prevalence of asthma and asthmatic symptoms than children not living near a highway. Besides, those children have higher prevalences of wheeze living in commercial area or industrial area than in other areas. There were a higher prevalence of asthma and dry cough among those families studied who owned their dwellings, than among those who leased their homes. Among the residences with different methods of building heating, the prevalence of asthma and asthmatic symptoms were also significantly different with these families having different types of heating. Those children living in homes with floor heating system have the lowest prevalence of asthma. In dwellings that use different types of fuel for cooking or having fume exhaust equipments in the kitchen and bathroom, there were significant differences in prevalence of asthma and dry cough with children of these families studied, while there were no significant differences in prevalence of wheeze with children of these families. Children living in those residences with air purifier showed a significantly higher prevalence of asthma and asthmatic symptoms than in other residences without the use of air purifier. Also the prevalence of dry cough was higher in families that have been using air-humidifier in their homes, than in homes that have not.

Table 5 shows associations between asthma and asthmatic symptoms and different building characteristics and usage rates of household HVAC by logistic regression analyses. Comparing to children living in DHSF, children living in MSAD was shown to be significantly more at risk of having doctor diagnosed asthma and had dry cough in the last 12 months. Comparing to children living in $\leq 60\text{ m}^2$ residences, children living in $61\text{--}100\text{ m}^2$ were more at risk in having doctor diagnosed asthma and dry cough (in the last 12

months). Comparing to children living in residences that were built before 1980, children in residences that were built after 1980 were shown to have a significantly less risk in having asthma and wheeze. Those children in residences that were within 200 m close to a highway or commercial area was shown to have a significantly higher risk of having suffered wheeze and dry cough. The family's ownership of the residence and the use of air conditioner for building heating were shown to be significantly associated with children's dry cough. The use of electric heater for building heating was significantly, positively associated with wheeze. The use of fume exhaust ventilator in the kitchen and exhaust fan in the bathroom was shown to have a negative but significant association with children having wheeze (ever). The use of exhaust fan in the kitchen was shown to have a negative but significant association with children's dry cough. Burning of wood as a fuel for cooking was shown to have a positive but significant association with asthma. The use of air purifier for improving indoor air quality in the residence was shown to have a positive but significant association with children having wheeze (ever and in the last 12 months) and dry cough (in the last 12 months).

Discussion

In this study, DHSF and MSAD were the main types of residences in Shanghai. The proportion of the residence in different sizes ($\leq 60\text{ m}^2$, $61\text{--}100\text{ m}^2$ and $\geq 101\text{ m}^2$) was almost equal. The largest proportion of residences was built from 1991 to 2005. Suburban residents would be more likely to live near a river or a lake or in an industrial area, but less likely in commercial areas than urban resident. In Shanghai, some residents still had no heating in their homes. Household air conditioners and electric room heaters were the main types of heating used for the majority of these dwellings. Furthermore, in majority of cases, natural gas and electricity have replaced coal to be the major fuels for household cooking. Some households have installed

Table 4. The prevalence of asthma and asthmatic symptoms in residences with different building characteristics and usage rates of HVAC.

Items	Asthma, doctor-diagnosed		Wheeze, ever		Wheeze, last 12 months		Dry cough, last 12 months	
	Prevalence (N, %)	P ^a	Prevalence (N, %)	P ^a	Prevalence (N, %)	P ^a	Prevalence (N, %)	P ^a
Type of the residence								
DHSF	248, 8.9		794, 27.4		630, 22.0		517, 18.0	
SDD	10, 6.8		39, 26.0		35, 23.5		27, 18.2	
MSAD	959, 11.0	0.002	2512, 28.6	0.567	1916, 21.8	0.872	1845, 21.0	0.002
Size of the residence (m²)								
≤ 60	404, 9.2		1288, 28.8		986, 22.0		771, 17.1	
61–100	500, 11.2		1265, 27.9		980, 21.6		974, 21.4	
≥ 101	404, 10.7	0.007	1098, 28.8	0.540	837, 22.0	0.878	779, 20.4	<0.001
Built period of the residence								
Before 1980	167, 13.6		390, 30.8		294, 23.3		233, 18.3	
1980–1990	149, 8.6		493, 28.3		387, 22.2		327, 18.6	
1991–2000	427, 10.6		1163, 28.5		895, 21.9		836, 20.4	
2001–2005	405, 11.2		1009, 27.8		782, 21.5		733, 20.2	
2006–present	149, 8.1	<0.001	522, 28.0	0.343	394, 21.2	0.649	369, 19.8	0.349
Surrounding environment of the residence (within 200 metres)								
High way	526, 11.1		1449, 30.4		1111, 23.3		997, 20.8	
	Yes		1929, 27.6	0.010	1488, 21.3	0.011	1334, 19.0	0.017
	No		389, 28.6		307, 22.6		292, 21.4	
River or lake	123, 9.2		2989, 28.8		2292, 22.0		2037, 19.5	
	Yes		1061, 30.3	0.152	822, 23.4	0.935	737, 21.0	0.099
	No		2312, 28.1		1775, 21.5	0.022	1591, 19.2	0.030
Commercial area	370, 10.7		283, 34.7	0.334	237, 29.0		182, 22.2	
	Yes		3088, 28.3	0.930	2359, 21.6	<0.001	2146, 19.6	0.064
	No							
Industrial area	80, 10.2							
	Yes							
	No							
Ownership of the residence								
Owner	877, 10.9		2294, 28.3		1752, 21.6		1694, 20.8	
Tenant	435, 9.4	0.005	1348, 28.5	0.808	1046, 22.1	0.514	824, 17.3	<0.001
Type of heating^b								
Air-conditioner	818, 10.0		2253, 27.2		1719, 20.7		1629, 19.6	
Electric heater	111, 12.0		303, 32.2		228, 24.2		189, 19.9	
Floor heating	6, 5.4		24, 21.4		18, 16.4		20, 18.0	
Others	24, 10.6		75, 33.5		64, 28.3		32, 14.0	
No heating	123, 8.2	0.016	411, 26.8	0.002	311, 20.2	0.004	244, 15.9	0.003

(continued)

Table 4. Continued.

Items	Asthma, doctor-diagnosed		Wheeze, ever		Wheeze, last 12 months		Dry cough, last 12 months	
	Prevalence (N, %)	P ^a	Prevalence (N, %)	P ^a	Prevalence (N, %)	P ^a	Prevalence (N, %)	P ^a
Fuel being used for cooking^c								
Coal	152, 12.4		371, 30.2		289, 23.4		271, 21.8	
Wood	8, 19.0		17, 36.2		11, 23.4		10, 21.3	
Natural gas	730, 9.9		2086, 27.8		1570, 20.9		1508, 20.1	
Electricity	218, 10.9		579, 28.5		463, 22.8		353, 17.3	
others	60, 10.8	0.019	156, 28.1	0.349	119, 21.3	0.178	107, 19.1	0.020
Exhaust equipments in the kitchen								
Fume exhaust ventilator	1050, 10.9		2756, 28.3		2124, 21.8		1998, 20.4	
Exhaust fan	54, 8.5		180, 27.6		139, 21.4		84, 12.8	
Both ^d	130, 9.4		400, 28.6		307, 21.9		275, 19.7	
None	85, 8.0	0.004	327, 30.0	0.671	240, 22.1	0.988	174, 15.8	<0.001
Exhaust fan in the bathroom								
Yes	2837, 28.0		2182, 21.5		2022, 19.9		1067, 10.6	
No	822, 30.0	0.040	632, 23.1	0.086	504, 18.4	0.068	248, 9.3	0.037
Use equipments for improving indoor air quality, stated below, in the residence								
Air-conditioner	Yes	1226, 10.5	3350, 28.3		2558, 21.6		2346, 19.7	
	No	42, 9.0	142, 29.9	0.450	118, 24.7	0.107	100, 20.7	0.586
Air-humidifier	Yes	239, 11.4	626, 29.7		482, 22.8		466, 22.1	
	No	1030, 10.2	2869, 28.1	0.135	2195, 21.5	0.177	1981, 19.3	0.004
Air-purifier	Yes	134, 13.8	331, 33.7		256, 26.0		244, 24.7	
	No	1134, 10.1	3159, 27.9	<0.001	2418, 21.3	0.001	2200, 19.3	<0.001
Air-Ionizer	Yes	16, 9.0	54, 30.0		38, 21.2		38, 21.1	
	No	1253, 10.4	3439, 28.4	0.626	2638, 21.7	0.875	2407, 19.8	0.650

DHSF: detached housings for single families; SDD: semi-detached dwelling; MSAD: multi-storey apartment dwelling.

^aChi-Square Test for the difference of prevalence between different building characteristics (n*2 times tables, classification for the diseases is Yes vs. No). Herein "n" depends on the classification of each building characteristics. For example, for the type or size of the residence, n = 3; for build period of the residence, type of heating, and fuel for cooking, n = 5.

^bThose residences, which only have one heating method, were selected to be analysed.

^cThose residences, which only have one type of fuel for cooking, were selected to be analysed.

^dFume exhaust ventilator and Exhaust fan.

Table 5. Association of asthma and asthmatic symptoms with different building characteristics and usage rates of HVAC.

Items	Asthma, doctor diagnosed		Wheeze, ever		Wheeze, last 12 months		Dry cough, last 12 months	
	OR (<i>p</i> ^a)	AOR, 95% CI (<i>p</i> ^a)	OR (<i>p</i> ^a)	AOR, 95% CI (<i>p</i> ^a)	OR (<i>p</i>)	AOR, 95% CI (<i>p</i> ^a)	OR (<i>p</i> ^a)	AOR, 95% CI (<i>p</i> ^a)
Type of the residence (DHSF = 1.00) ^b								
MSAD	1.27 (0.001)	1.20, 1.01–1.43 (0.034)	1.04 (0.401)	0.97, 0.88–1.08 (0.735)	0.99 (0.838)	0.93, 0.84–1.04 (0.293)	1.21 (0.001)	1.11, 0.98–1.26 (0.093)
Size of the residence ($\leq 60 \text{ m}^2 = 1.00$)								
61–100	1.24 (0.002)	1.21, 1.03–1.42 (0.022)	0.96 (0.340)	0.92, 0.83–1.03 (0.183)	0.98 (0.651)	0.95, 0.84–1.06 (0.378)	1.32 (<0.001)	1.25, 1.11–1.41 (<0.001)
≥ 101	1.18 (0.027)	0.98, 0.82–1.17 (0.560)	1.00 (0.967)	0.98, 0.87–1.09 (0.933)	1.00 (0.993)	0.98, 0.86–1.11 (0.804)	1.25 (<0.001)	1.14, 1.00–1.29 (0.044)
Built period of the residence (Before 1980 = 1.00)								
1980–1990	0.60 (<0.001)	0.65, 0.50–0.84 (0.013)	0.88 (0.133)	0.87, 0.73–1.04 (0.480)	0.94 (0.487)	0.90, 0.75–1.09 (0.875)	1.02 (0.843)	1.00, 0.81–1.22 (0.423)
1991–2000	0.76 (0.005)	0.81, 0.65–1.00 (0.050)	0.89 (0.113)	0.87, 0.74–1.01 (0.485)	0.92 (0.304)	0.88, 0.75–1.04 (0.675)	1.14 (0.111)	1.10, 0.92–1.31 (0.105)
2001–2005	0.81 (0.034)	0.76, 0.61–0.94 (0.018)	0.86 (0.042)	0.81, 0.68–0.95 (0.012)	0.90 (0.195)	0.79, 0.66–0.95 (0.012)	1.13 (0.156)	1.05, 0.88–1.25 (0.644)
2006–present	0.57 (<0.001)	0.63, 0.48–0.84 (0.002)	0.88 (0.100)	0.83, 0.67–1.02 (0.073)	0.88 (0.166)	0.81, 0.65–1.01 (0.067)	1.10 (0.305)	1.03, 0.82–1.30 (0.791)
Surrounding environment of the residence (within 200 meters) (None = 1.00) ^c								
High way	1.07 (0.491)	1.20, 0.95–1.51 (0.159)	1.24 (0.003)	1.20, 1.02–1.41 (0.023)	1.21 (0.018)	1.19, 1.00–1.42 (0.056)	1.25 (0.006)	1.22, 1.02–1.46 (0.018)
River or lake	0.80 (0.153)	0.92, 0.65–1.32 (0.891)	1.17 (0.129)	1.13, 0.89–1.43 (0.331)	1.19 (0.129)	1.19, 0.92–1.54 (0.201)	1.30 (0.025)	1.29, 0.99–1.67 (0.083)
Commercial area	1.03 (0.821)	1.03, 0.80–1.33 (0.882)	1.28 (0.001)	1.32, 1.11–1.57 (0.002)	1.27 (0.005)	1.35, 1.12–1.64 (0.001)	1.33 (0.001)	1.22, 1.00–1.48 (0.038)
Industrial area	0.76 (0.193)	1.12, 0.65–1.92 (0.962)	1.32 (0.030)	1.25, 0.89–1.74 (0.154)	1.47 (0.005)	1.39, 0.98–1.99 (0.052)	1.28 (0.085)	1.29, 0.88–1.87 (0.352)
Ownership of the residence (Tenant = 1.00)								
Owner	1.19 (0.005)	1.16, 1.01–1.33 (0.041)	0.99 (0.808)	0.95, 0.88–1.04 (0.807)	0.97 (0.514)	0.94, 0.85–1.03 (0.518)	1.25 (<0.001)	1.18, 1.07–1.30 (0.001)
Type of heating (No heating = 1.00) ^d								
Air-conditioner	1.24 (0.036)	1.04, 0.84–1.30 (0.992)	1.02 (0.745)	1.01, 0.88–1.16 (0.810)	1.03 (0.616)	1.06, 0.91–1.23 (0.282)	1.29 (<0.001)	1.21, 1.03–1.42 (0.014)
Electric heater	1.53 (0.003)	1.31, 0.97–1.78 (0.235)	1.30 (0.005)	1.25, 1.03–1.52 (0.037)	1.26 (0.022)	1.26, 1.02–1.56 (0.037)	1.32 (0.017)	1.21, 0.96–1.52 (0.223)

(continued)

Table 5. Continued.

Items	Asthma, doctor diagnosed		Wheeze, ever		Wheeze, last 12 months		Dry cough, last 12 months	
	OR (<i>p</i> ^a)	AOR, 95% CI (<i>p</i> ^a)	OR (<i>p</i> ^a)	AOR, 95% CI (<i>p</i> ^a)	OR (<i>p</i>)	AOR, 95% CI (<i>p</i> ^a)	OR (<i>p</i> ^a)	AOR, 95% CI (<i>p</i> ^a)
Floor heating	0.64 (0.277)	0.41, 0.17–1.01 (0.064)	0.75 (0.190)	0.77, 0.47–1.27 (0.421)	0.77 (0.305)	0.86, 0.49–1.50 (0.666)	1.17 (0.569)	0.97, 0.56–1.66 (0.902)
Fuel being used for cooking (Electricity = 1.00) ^c								
Coal	1.16 (0.222)	0.96, 0.75–1.23 (0.691)	1.08 (0.311)	1.03, 0.86–1.22 (0.436)	1.04 (0.678)	1.02, 0.85–1.23 (0.473)	1.33 (0.002)	1.24, 1.01–1.51 (0.038)
Wood	1.92 (0.084)	2.84, 1.24–6.54 (0.026)	1.42 (0.353)	1.55, 0.79–3.03 (0.463)	1.03 (0.864)	1.09, 0.51–2.34 (0.780)	1.29 (0.434)	0.85, 0.35–2.06 (0.819)
Natural gas	0.89 (0.157)	0.86, 0.72–1.02 (0.087)	0.97 (0.537)	0.96, 0.85–1.08 (0.931)	0.90 (0.067)	0.89, 0.79–1.01 (0.258)	1.20 (0.005)	1.17, 1.01–1.34 (0.033)
Exhaust equipments in the kitchen (None = 1.00)								
FEV	1.41 (0.005)	1.24, 0.96–1.60 (0.057)	0.92 (0.264)	0.85, 0.73–0.99 (0.029)	0.98 (0.837)	0.94, 0.80–1.11 (0.534)	1.37 (<0.001)	1.21, 1.00–1.47 (0.053)
Exhaust fan	1.07 (0.864)	1.00, 0.67–1.50 (0.985)	0.89 (0.292)	0.91, 0.72–1.16 (0.934)	0.96 (0.732)	1.03, 0.80–1.33 (0.784)	0.78 (0.068)	0.70, 0.52–0.96 (0.021)
Both ^e	1.19 (0.274)	0.95, 0.69–1.32 (0.901)	0.94 (0.476)	0.88, 0.72–1.07 (0.509)	0.99 (0.958)	0.98, 0.79–1.21 (0.974)	1.30 (0.014)	1.09, 0.87–1.38 (0.394)
Exhaust fan in the bathroom (No = 1.00)								
Yes	1.17 (0.037)	1.12, 0.94–1.32 (0.198)	0.91 (0.040)	0.86, 0.78–0.95 (0.004)	0.92 (0.086)	0.87, 0.78–0.97 (0.013)	1.11 (0.068)	1.05, 0.93–1.18 (0.277)
Have the equipments for indoor air quality, stated below, in the residence (No = 1.00)								
Air-conditioner	1.18 (0.304)	1.13, 0.79–1.60 (0.512)	0.93 (0.450)	0.92, 0.74–1.15 (0.475)	0.84 (0.107)	0.85, 0.68–1.08 (0.178)	0.94 (0.586)	0.93, 0.73–1.19 (0.572)
Air-humidifier	1.14 (0.096)	1.00, 0.86–1.18 (0.994)	0.98 (0.135)	0.99, 0.88–1.11 (0.651)	1.08 (0.177)	1.01, 0.90–1.14 (0.848)	1.18 (0.004)	1.09, 0.97–1.23 (0.148)
Air-purifier	1.42 (<0.001)	1.20, 0.98–1.47 (0.074)	1.32 (<0.001)	1.24, 1.06–1.44 (0.006)	1.30 (0.001)	1.21, 1.03–1.43 (0.021)	1.37 (<0.001)	1.22, 1.04–1.43 (0.013)
Air-Ionizer	0.85 (0.543)	0.74, 0.43–1.27 (0.767)	1.08 (0.626)	1.00, 0.71–1.41 (0.979)	0.97 (0.875)	0.88, 0.60–1.30 (0.388)	1.09 (0.650)	0.92, 0.63–1.36 (0.900)

DHSF: detached housings for single families; MSAD: multi-storey apartment dwelling; FEV: Fume exhaust ventilator.

^a*p* values in significant test are corresponded in the parenthesis. All of significant odds ratios^b(*p* < 0.05) are bold.^cThose residences, which only have one mentioned surrounding environment, were selected to be analyzed.^dThose residences, which only have one heating method, were selected to be analyzed.^eThose residences, which only have one type of fuel for cooking, were selected to be analyzed.^fFume exhaust ventilator and Exhaust fan.

equipment for improving indoor air comfort or quality, such as the air humidifier and air purifier, and these are now widely used in Shanghai. Urban usages of these equipments are more widespread than in suburban areas. All these changes in surrounding environments and uses of household equipments could therefore have possibly posed an effect on children's health, when considering the increasing prevalence of respiratory symptoms being reported in Shanghai and China.³ The divergences of environmental exposures in different districts perhaps could have a significant association with this result. Children in those residences that were built after 1980 were shown to have significantly less risk in having asthma and wheeze than those living in residences that were built before 1980. Those residences that were within 200 m close to a highway or commercial area were shown to have significantly positive associations with children having suffered wheeze and dry cough. The use of electric heater for building heating could have significantly positive associations with children having wheezing symptom, while the use of wood as a fuel for cooking could have a positive and significant association with asthma. The use of mechanical ventilation in a kitchen or bathroom could reduce children's risk in suffering wheezing symptoms. However, the use of air purifier could have a significant and positive association with children's wheeze and dry cough.

The analysis and results of this study was based on the large-scale CCHH survey with a high response rate of 85.3%. Among those districts included for the study, the sample sizes, as shown in Table 1, were so large that the risk of reporting bias would probably be very low in different analyses. To eliminate the confounding factors from other notably associated factors for children's health, all these factors were adjusted by multiple logistic regression analysis. To avoid the interferences between each other in the variables that can have more than one alternative (such as surrounding environment, types of building heating and fuel being used for cooking), those residences which only have one alternative in each variable were selected to be analysed as shown in Table 5. However, because this study was a cross-sectional questionnaire study and had no home inspection, parents' personal reports and divergence in understanding of these questions could have possibly an influence in the accuracy of those answers to the questionnaire.

In 2011, Sundell et al.¹⁹ found that indoor ventilation rates were significantly and negatively associated with childhood asthma and asthmatic symptoms. Although such association was not directly analysed in this study, we also could infer that indoor ventilation was probably associated with children's health in Shanghai, because the types and sizes of the residence

could have an obvious association with indoor ventilation, while indoor exhaust equipments are directly related with indoor ventilation rates. We found that children living in densely populated multi-storey apartments were more at risk in having asthma and dry cough than those living in SDD. Although the association between the size of the residence and children's health seemed to be converse with people's general considerations, the results of our study found that children's disease and symptoms probably have an obvious association with the family's socio-economic status.^{14,16–18} The families, who own their residences would live in larger residences, perhaps would have higher socio-economic status and would be more sensitive to children's health than others. Thus, the children in these families would take more medical care than those children of those families without ownership of their residences or/and are living in smaller residences. The expressive symptoms for asthma (wheeze) for these children would be better cared for and are often relieved by better medical care; and therefore less instances of wheeze would be reported than in other families.

The purpose of natural or mechanical ventilation is mainly to draw in outdoor air to improve indoor air quality of residences and exhaust indoor air pollution to outdoors. In this study, equipment for ventilation in the kitchen or bathroom was shown to have a significant and negative association with wheeze symptom. Therefore, the increase in home ventilation would probably have improved indoor air quality, thus would reduce occurrence of asthmatic symptoms. According to results of this study, we also could infer that both outdoor air quality and indoor air quality could have significant effects on children's asthma and asthmatic symptoms. Those residences that are within 200 m close to a highway, commercial area and industrial area would be exposed to possibly bad outdoor air quality than other residences. We found that homes being within 200 m close to a highway have a significant and positive association with childhood wheeze and dry cough. These are also reported by many other studies.^{10,11,20–22} Besides, the many factors which can influence indoor air quality could have a significant association with asthma and asthmatic symptoms and this was illustrated by our study and supported by other studies.^{23,24} The homes that were built before 1980 would have more home dampness-related exposures and thus have more bad indoor air quality than other residences that were built after 1980.⁹ As with a similar global study,²⁷ the use coal for cooking was found to have a significant association with suffering dry cough during the last 12 months, and the use of wood for cooking has also a significant association with children's asthma. By considering the health effect of

bad indoor air quality, we found that residents of Shanghai, especially those living in urban districts and have family history of asthmatic symptoms, perhaps would have an obvious ambition to improve their indoor air quality by using a suitably appropriate household air purifier. Thus, the results showed that the use of air purifier could have a significant and positive association with children's wheeze symptoms and dry cough. A study conducted in New York, from 2002 to 2003,²⁸ also revealed that the use of air purifier, air humidifiers and other humidified equipments in the residence was significantly and positively associated with children's asthmatic symptoms. However, although air cleaners in certain styles and functions could have an outstanding effectiveness in purifying the indoor air, it could not indicate whether they would alleviate the related symptoms incurred after exposure to indoor air pollutants and allergens.^{29,30} The effectiveness of these equipments was related to their particular function, the location of installation and the status of operation.³¹ Thus, families should be careful in selecting and using the right household air purifier fit for their needs in their homes.

Conclusion

Building characteristics, surrounding environments (highway, commercial area or industrial area) and household equipments for home ventilation or for improvement of indoor air quality could have a notable association with childhood asthma and asthmatic symptoms in Shanghai. Outdoor and indoor air quality should be simultaneously considered for improvement to safeguard the health of children in Shanghai. Improving the home mechanical ventilation in the current residences could possibly reduce the risk of suffering wheeze and dry cough. The dwellings should not be designed or built close to the highway to enable a good living environment for children and families.

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