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Air change rates at night in northeast Chinese homes

Jing Hou, Yufeng Zhang, Yuexia Sun*, Pan Wang, Qingnan Zhang, Xiangrui Kong, Jan Sundell

Tianjin Key Laboratory of Indoor Air Environmental Quality Control, School of Environmental Science and Engineering, Tianjin University, Tianjin, 300350, China

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ABSTRACT

Air change rate data for dwellings in China are scarce. We carried out a study of ventilation rates in 399 homes in Tianjin and Cangzhou, China. Carbon dioxide concentration was continuously measured for 24 h in bedrooms and living rooms. The air change rate at night was calculated using a single zone mass balance model. In the whole home, the median air change rates during sleeping time for spring, summer, autumn and winter were 0.27 h^{-1}, 1.11 h^{-1}, 0.29 h^{-1}, 0.30 h^{-1}. In the child's bedroom with closed window and door, the median air change rates during sleeping time for spring, summer, autumn and winter were 0.25 h^{-1}, 0.25 h^{-1}, 0.30 h^{-1}, 0.37 h^{-1}. Air change rates in homes with open windows were significantly higher than those in homes with closed windows ($p = 0.000$).

1. Introduction

Ventilation of buildings, the exchange of “fresh” outdoor air for polluted indoor air, is important for health and comfort. An insufficient supply of outdoor air means higher concentrations of indoor generated pollutants. For example, air change rate directly influences the concentrations of VOCs, dust mite allergens and radon [1–3]. There is evidence that lower air change rates can negatively affect human health [4–6]. However, the focus in science during the last 40 years has been on minimizing energy use [7], with relatively little attention given to ventilation and its relation to health [4,5,8]. For example, the preoccupation with energy conservation means that in a cold climate, where outdoor air must be heated, warmed indoor air is conserved by reducing air change rate, decreasing the permeability of the enclosure and improving the thermal insulation of the enclosure.

Information on ventilation rates in buildings, and especially in homes, is very limited in China. The China, Children, Homes and Health (CCHH) study [9,10] has been designed to obtain detailed information on ventilation rates in homes.

Measurement of air change rates in residential buildings is challenging. Often measurements have been made with passive tracer gas techniques (PFT) or the tracer gas decay method. The accuracy of these methods has been widely discussed [11–13]. Among the difficulties in obtaining reliable measurements is that air change rates may differ from room to room, depending on weather conditions, building characteristics and occupants' behavior.

Available reports from large scale studies of air change rates in residential homes, to the best of our knowledge, are listed in Table 1.

Air change rates are affected by outdoor temperature, wind speed and direction, permeability of buildings and occupants' behavior [20–24]. In northeastern China, monsoon winds dominate the climate, which leads to considerable temperature differences between winter and summer. The north of China is cold and dry in the winter and warm and moist in the summer. Almost all homes in China have “natural ventilation.” This does not mean a system for natural ventilation, as in, for example, the Nordic countries, where homes have an inflow of air through devices in or around the windows, and exhaust ducts. In China there is only infiltration, and opening of windows. Most exhaust ducts are in the kitchen and bathroom. There is no air supply system.

Many Western countries have regulations or guidelines on ventilation of homes [25]. An air change rate of 0.5 h^{-1} is the minimum requirement in many building codes, e.g. in the Danish code (DS 418: 2002 [26]). Swedish Building regulations [27] require that rooms shall have a continuous 0.35 $l/s/m^2$ outdoor air inflow to a dwelling when occupied. This corresponds to an air change rate of 0.5 h^{-1} in a room with a height of 2.5m. Chinese standards for indoor air quality require that the ventilation rate should be more than 30 m^3/h/person for residential buildings [28]. This corresponds to 0.5 h^{-1} in a typical three person home with a volume of 180 m^3.

This study aims to provide a database of the distribution of air change rates in residential buildings in the northeast of China, and to characterize associations of air change rate with climate and human behavior. Further analyses on associations between air change rates and health outcomes will be reported.

* Corresponding author.
E-mail address: yuexiasun@tju.edu.cn (Y. Sun).

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Table 1
Large scale ventilation measurements in residential buildings.

Reference	Location	Number of residences	Tracer gas and measurement duration	Measured period	(Mean or median) Air change rates (h^{-1})	Comments
[14]	Finland	242 homes	PFT, 2-week	1988.11–1989.4	0.52	Mean
					0.41	Natural ventilation, mean
[15] (reported also in Ref. [16])	Sweden	1143 homes	PFT	1991.11–1992.4	0.33[a]	Single-family houses with natural ventilation, mean
					0.48[a]	Apartments with natural ventilation, mean
[16]	Norway	344 homes	PFT, 14-day	1992.05–1995.05, excluding the summer months	0.73[a]	Apartments with natural ventilation, mean
					0.68[a]	Single family houses with natural ventilation, mean
[17]	Sweden	540 infants' homes	PFT, 4-week	1994–1996, winter	0.68	Mean
[18]	US	509 homes	PFT, 2-day	1999–2001	0.71	Median
					0.87	California, median
					0.88	New Jersey, median
					0.47	Texas, median
[6]	Sweden	390 homes	PFT, 1-week	2001.10–2002.04	0.36	Single-family houses, mean
					0.48	Multi-family houses, mean
					0.37	Single-family houses with natural ventilation, mean
					0.34	Single-family houses with natural ventilation, bedroom, mean
[19]	France	567 homes	CO_2, nighttime	2003.10–2005.12	0.44	Median
[20]	Denmark	500 children's homes	CO_2, Nighttime	2008.03–2008.05	0.46	Bedrooms, geometric mean
					0.62	Bedrooms, arithmetic mean

[a] Converting unit from 'l/s. m^2' to 'h^{-1}' corresponding room with a height of 2.5m.

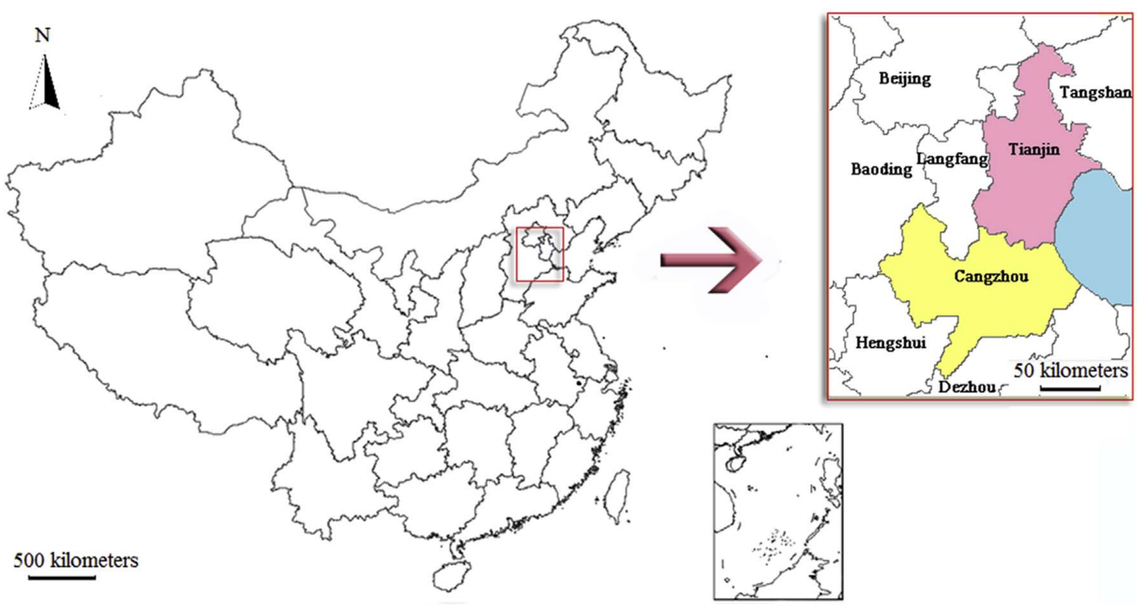

Fig. 1. Location of Tianjin and Cangzhou, China.

2. Methods

This study is part of the CCHH project (China, Children, Homes, Health) on the impact of the indoor environment on asthma and allergy among children in China [9,29]. The study consists of two phases. Phase I (May 2013–Dec. 2014) was a cross-sectional questionnaire investigation involving 7865 children who lived in Tianjin or Cangzhou. On a basis of Phase I data, Phase II (Sept. 2013–Jan. 2016) was a nested case-control investigation involving 410 children who lived in Tianjin city and Cangzhou village, and included home investigations and measurements. The cases were children with asthma and allergy, while controls were children without any allergic symptoms. The present study is based on Phase II measurements and observations.

Tianjin has a population of about 15 million, and Cangzhou's population is about 7 million. Cangzhou is situated about 100 km from Tianjin. The average wind speeds in summer and winter in Tianjin are 2.2 m/s and 2.4 m/s respectively, with the southwest wind as the dominant orientation [30]. The average outdoor air temperatures for spring, summer, autumn and winter are 13.4 °C, 25.7 °C, 13.6 °C and −1.7 °C in Tianjin [31]. Heating degree-day is about 2000 °C d based on 18 °C, while cooling degree-day is 124 °C d based on 26 °C [32]. Cangzhou's climate is almost identical to that of Tianjin. Tianjin is an important and developed city in China, one of four metropolitan areas that have provincial status, while Cangzhou is a less developed city.