

# Factors influencing indoor PM<sub>2.5</sub> concentration in rural houses of northern China

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**Abstract.** In traditional houses in rural areas of Northern China, most traditional heating systems, heated by mini-stove in the kitchen, usually take agricultural residues as fuels resources. Besides, burning cave under the ground-floor of a rural house is also widely used. The higher PM<sub>2.5</sub> concentration is crisis for human health. In this study, PM<sub>2.5</sub> concentration, temperature, relative humidity inside and outside the houses have been measured, moreover the factors impact on I/O rate coefficient has been discussed. The results show that the I/O rate coefficient in the evening is 2.5 times greater than the I/O rate coefficient in the daytime. I/O rate coefficient of PM<sub>2.5</sub> concentration is positive related to air temperature difference between indoor and outdoor. In addition, the impact of outdoor wind speed and predominant wind direction on the PM<sub>2.5</sub> emission has been studied.

## 1. Introduction

For thousands of years, Chinese people live in harmony with the nature and adhere to the principle that local circumstances should be adapted to the climate change, which has been proved by house construction modes, energy consumption modes, and indoor environment control strategies. With the change of times, the forms of dwellings for residents living in are constantly updated and developed. At the same time, in order to adapt to the harsh outdoor climatic and environmental changes, the reasonable optimized approaches of rural houses design are of great significance for people to live in the cold winter, which also show the constant practice of human wisdom. As shown in Figure 1, the original form of Chinese residential northern cold region could be traced back to ancient times, when people lived in the rocks or caves for social life, relying on a simple way of direct firing heating in winter [1]. In order to increase the privacy of a family, civil engineering structures began to develop gradually until Shang Dynasty; at the same time, using the high temperature gas flames to heat the heating facilities begun to emerge, such as “heating-wall” and “Di-Huolong”. Besides, kang was invented in order to make the heating surface warmer and obtain better heating effect on human bodies, by which the direct contact area could be much bigger [2]. Chinese people’s living styles and history cultures have been significantly affected by traditional heating approaches such as kangs, smoke heated walls and grounded kang (burning cave), which utilize biomass (crop wastes collected from farmland and excrements from animals) to heat the rooms in a long and severe cold winter in vast northern China. Different kangs are taken as the prototypes of radiation heating systems, which have been used since 10,000 B.C [2]. They are not only domestic heating systems, but also provide places for cooking, eating, sleeping and communications. In order to meet the needs of modern variety architectural space layouts, square-shaped, L-type and other forms of kangs have appeared in different



houses, and have been in use ever since. Thus, technological improvements closed to people's daily life have been carried out on these original heating systems, which reflect people's wisdom.

In recent years, Chinese academia and general public spark a debate and discussion over the necessity of keeping the traditional heating approaches due to its low thermal efficiency, poor indoor air quality, harm to human health and rapid urbanization. People advocating for the traditional heating approaches present the following evidence: (1) the households of traditional heating houses are approximately 166 million in northern China [3]; (2) the energy crisis and serious environmental pollution could be aggravated by the use of central heating system in widely dispersed houses in rural areas [4]; (3) a lot of biomass resources could not be efficiently used and crop wastes are disposed only by open burning on the farmland, which would cause serious air pollution and traffic accidents. Thus, to achieve sustainable development of Chinese society, traditional heating methods are irreplaceable today in the rural areas of northern China in winter with low-energy consumption and low cost. Increasing thermal efficiency of traditional heating systems and improving indoor living environment has already become an important research subject. A large number of field surveys, experimental and theoretical researches on the forms and constructions, and integrated application modes of traditional heating systems like kang and burning caves have been conducted [5-12]. From a historical point of view, this study focuses on outdoor climate, the integrated application of traditional heating systems in dwellings, indoor thermal effects on human bodies, and comfortable postures have been measured and discussed. Rural houses in Shenyang, Fuxin and Dalian in Liaoning Province of China have been taken as research objects.

## 2. Methodology

### 2.1. Basic conditions

According to the climate zoning in China, Fuxin is located in the northeastern part of China, and belong to the severe cold region. Based on the meteorological statistics of the recent 40 years between 1971 and 2010 in reference [13], it shows that the days with daily average temperatures lower than 5°C in Fuxin rural areas were about five months. In addition, extremely low temperature could reach to -29.4°C-27.1°C [14]. Moreover, the testing houses are located in a village, and far away from roads. There has no pollution sources outside the houses.

The PM<sub>2.5</sub> diffusion is significant influenced by the predominant wind direction in cold winter. The wind velocity is from 0.5 m/s to 1.5 m/s, and typical chimney diameter is 100mm, the amount of flue gas in heating and cooking is approximately from 14 to 42 m<sup>3</sup>/(h·household). PM<sub>2.5</sub> emission is from 1.536 million households of Fuxin. The PM<sub>2.5</sub> diffusion from the smoke exhausting system of the heating house is also significant influenced by the wind speed in cold winter. The correlation coefficient between PM<sub>2.5</sub> concentration and wind speed is about 0.23 [15].

### 2.2. Methods

As shown in Figure 1, PM<sub>2.5</sub> concentrations of the four typical rural houses in northern china heated by traditional heating systems have been measured. And the plane of different house is in Figure 2. In addition, indoor and outdoor PM<sub>2.5</sub> concentration and temperatures have been measured and analyzed. These houses were located in Hapeng location, Fuxin city, Liaoning Province, shown in Figure 1. The study period was from Dec.6, 2013 to Dec.7, 2013.

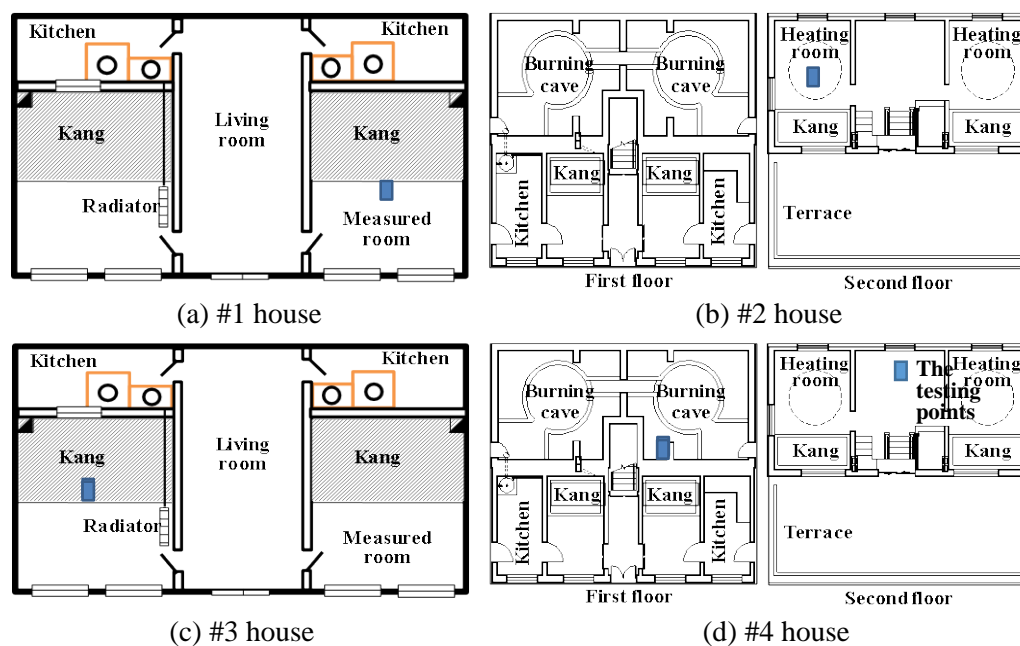
According to the testing requirements in "Ambient Air Quality Standard"(DEP 2012), SHINYEI PM<sub>2.5</sub> Sensor assessment monitors have been used for measuring PM<sub>2.5</sub> concentration, and recording with 1 minute interval, which have highly testing accuracy about 85%, and broader measurement range from 0μg/m<sup>3</sup> to 500μg/m<sup>3</sup>. The CO concentration has been recorded by indoor air quality-TSI7545. The indoor and outdoor temperature and relative humidity have been measured by thermo recorder TR-72U. The instruments collect data during heating days, inside and outside all four houses.

Test conditions are including the following four parts: (1) Windows and doors were closed, heating stoves often do not work after 21:00; (2) Windows and doors were closed, stoves work in the daytime;

(3) Windows and doors were open, heating stoves often do not work after 21:00; (4) Windows and doors were open, stoves work in the daytime.



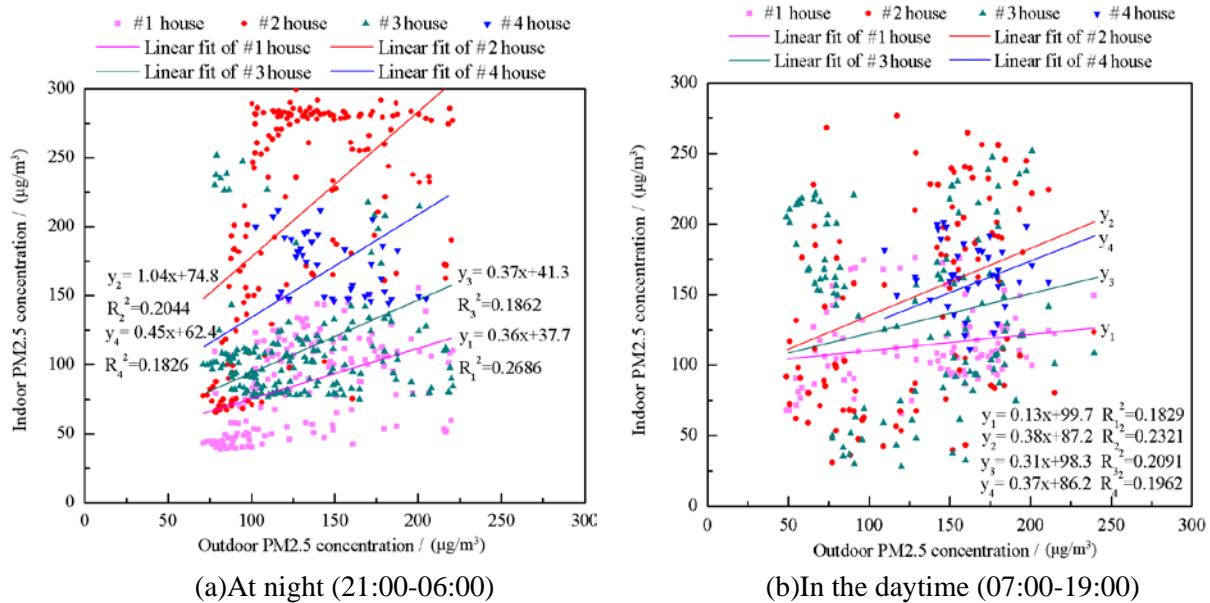
**Figure 1.** Measured houses.



**Figure 2.** Plane of measured house.

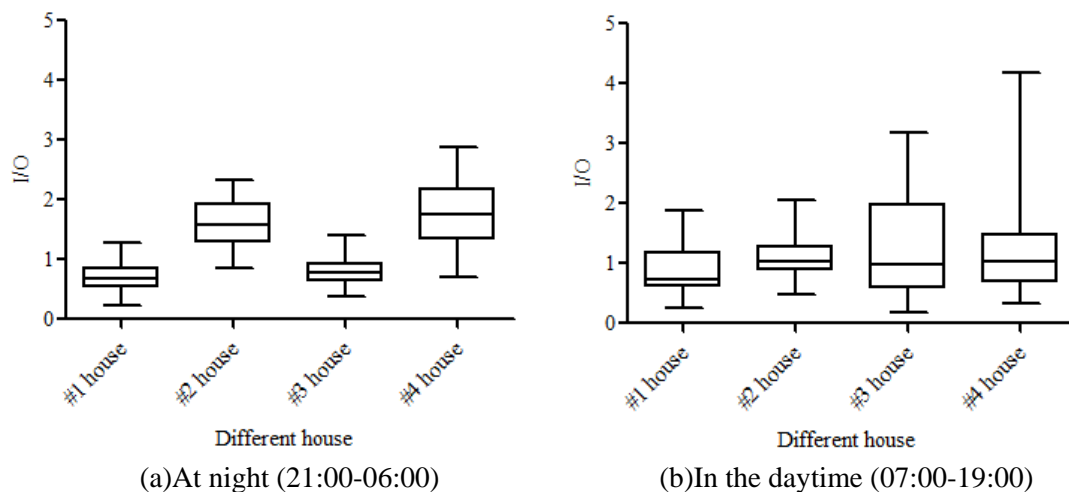
### 3. Results and discussions

By using Origin 8.0, I/O rate coefficient is convenient to estimate the relationship between indoor and outdoor PM<sub>2.5</sub> concentration. As measured results described in Figure 3, the outdoor PM<sub>2.5</sub> concentration is between 50~250 $\mu\text{g}/\text{m}^3$ . The indoor PM<sub>2.5</sub> concentration is between 50~300 $\mu\text{g}/\text{m}^3$ . According to the comparison on Figure 3(a) and Figure 3(b), the I/O rate coefficient in the evening is between 0.36 $\mu\text{g}/\text{m}^3$  and 1.04 $\mu\text{g}/\text{m}^3$ , the evening rate coefficient was 2.5 times greater than the day rate coefficient. The indoor PM<sub>2.5</sub> concentration in the evening is significant influenced by outdoor PM<sub>2.5</sub> concentration. Because that the main pollution source is generated on cooking time, while using heating stove integrated with kang.



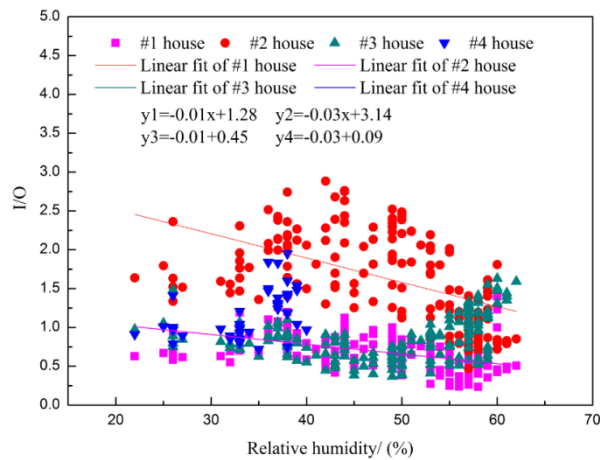
**Figure 3.** The relationship of PM<sub>2.5</sub> concentration between indoor and outdoor environment.

As measured results are shown in Figure 4, Average I/O rate coefficient of PM<sub>2.5</sub> concentration at night is between 0.6-1.7. Average I/O rate coefficient of PM<sub>2.5</sub> concentration in the daytime is about 1. It could confirm that ventilation by opening the door in the daytime is an effective approach for decreasing the indoor PM<sub>2.5</sub> concentration.

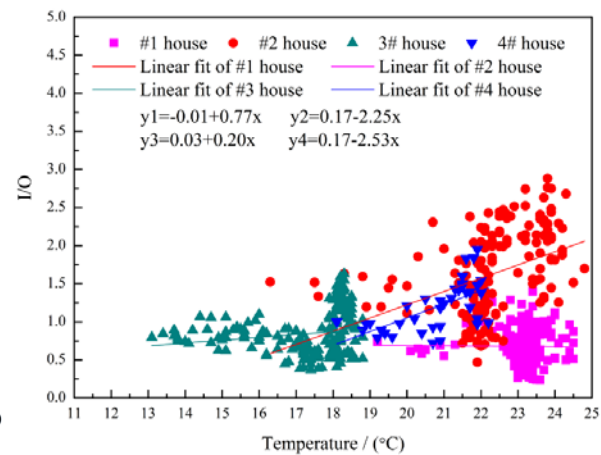


**Figure 4.** The I/O rate comparison.

According to measured results in Figure 5 and Figure 6, which can illustrate that I/O rate coefficient of PM<sub>2.5</sub> concentration is negatively related to the indoor air relative humidity. Besides, I/O rate coefficient of PM<sub>2.5</sub> concentration is nearly positive correlation with air temperature difference between inside and outside the house. Moreover, the results is similar to Wan's results [16].

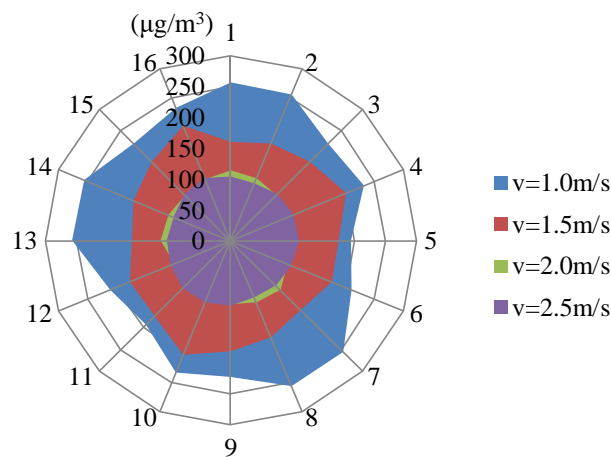


**Figure 5.** Relative humidity impacts on I/O.



**Figure 6.** Temperature difference impacts on I/O.

According to measurements, as shown in Figure 7, as the wind velocity is increased, the I/O rate coefficient is decreased. This conclusion confirmed by field experiments in future studies.



**Figure 7.** The impacts of wind direction and velocity on I/O rate coefficient.

#### 4. Conclusions

Some significant conclusions are as follows:

(1) The I/O rate coefficient in the evening is  $0.66\mu\text{g}/\text{m}^3$  higher than the I/O rate coefficient in the daytime. It confirmed that ventilation by opening the door in the daytime is an effective approach for decreasing the indoor PM<sub>2.5</sub> concentration.

(2) I/O rate coefficient of PM<sub>2.5</sub> concentration is negatively related to the indoor air relative humidity.

(3) I/O rate coefficient of PM<sub>2.5</sub> concentration is nearly positive correlated with air temperature difference between indoor and outdoor.

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