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# Wintertime pollution level, size distribution and personal daily exposure to particulate matters in the northern and southern rural Chinese homes and variation in different household fuels☆

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ABSTRACT

This study investigated and compared wintertime air pollution and personal exposure in the rural northern and southern Chinese homes. Daily indoor and outdoor particle samples were simultaneously collected by using stationary samplers, and personal exposure was directly measured using portable carried samplers. The daily average concentrations of indoor and outdoor $PM_{2.5}$ were 521 ± 234 and 365 ± 185 μg/m$^3$ in the northern village, that were about 2.3–2.7 times of 188 ± 104 and 150 ± 29 μg/m$^3$ in indoor and outdoor air in the southern villages. Particle size distribution was similar between indoor and outdoor air, and had relatively smaller difference between the two sites, relative to the particle mass concentration difference. $PM_{2.5}$ contributed to ~80% of the TSP mass, and in $PM_{2.5}$, near 90% were $PM_{1.0}$. In homes using electricity in the southern villages, outdoor air pollution could explain 70–80% of the variation in indoor air pollution. The daily exposure to $PM_{2.5}$ measured using personal carried samplers were 451 ± 301 μg/m$^3$ in the northern villages with traditional solid fuels used for daily cooking and heating, and in the southern villages without heating, the exposure to $PM_{2.5}$ were 184 ± 83 and 166 ± 45 μg/m$^3$, respectively, for the population using wood and electricity for daily cooking. Time-weighted daily average exposure estimated from area concentration and time spent indoor and outdoor was generally correlated the directly measured exposure.



## 1. Introduction

Nowadays in China, clean fuels, such as electricity and gases, are becoming popular in some rich homes, even in rural areas under a rapid socio-economic development and fast urbanization rates in the country (Duan et al., 2014). Despite this, traditional solid fuels, such as coal and biomass fuels, are still widely used by nearly 60% of the Chinese population and will still be the dominant primary energy for the foreseeable future in rural China. The high consumption, together with the relatively low burning efficiency, produces high amounts of many air pollutants such as CO, primary Particulate Matter (PM), Black Carbon (BC), Organic Carbon (OC) and toxic organics such as polycyclic aromatic hydrocarbons (Chen et al., 2005; Li et al., 2017; Shen et al., 2010, 2011; Huang et al., 2014). This not only results in high pollution levels in indoor air (Zhang and Smith, 2007) but also contributes to outdoor air pollution (Butt et al., 2016; Lelieveld et al., 2015), leading to severe Household Air Pollution (HAP) and adverse health outcomes (Chafe et al., 2014; Lelieveld et al., 2015; Lim et al., 2012; WHO, 2014). Globally, exposure to HAP caused approximately four million premature deaths and about 1 million were in China (WHO, 2014; Lim et al., 2012).

Although severe air pollution and high pollution haze episodes have received widespread concern, most available studies and controls are focused on air pollution in urban regions and mega/large cities, whereas household air pollution in rural areas and household combustion sources are highly underappreciated in current studies and air pollution controls (Liu et al., 2016). The

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country will find it difficult to achieve its clean air goals without emphasis and controls on household air pollution in rural areas (Downward et al., 2014; Shen, 2016; Edwards et al., 2007). A recent study found that elimination of residential sources in the Beijing-Tianjin and Hebei (BTH) region in China annual emissions of primary $PM_{2.5}$ can be reduced by 32%, much higher than the reductions by eliminating other sources (Liu et al., 2016).

In China, many indoor air pollution measurements were conducted during the 1980s; unfortunately, few were conducted in the 1990s (Zhang and Smith, 2007). With increased concerns about this serious problem, some studies were done during the last twenty years, most after 2010 (Alnes et al., 2014; Baumgartner et al., 2011; Chowdhury et al., 2013; Chen et al., 2015, 2016a; Ding et al., 2012; Fischer and Koshland, 2007; He et al., 2005; Wang et al., 2010; Zhong et al., 2012). However, such studies are still very limited giving a large temporal-spatial variation in China. For example, during cold winters, solid fuels are often used for household heating in the northern areas, but not in the southern regions. This results in distinct pollution levels and risk between the southern and northern areas. The life expectancies were found to be ~5.5 years lower in the north compared to the south (Chen et al., 2013).

In the present study, a field campaign was conducted to investigate and compare HAP and personal daily exposure among rural residents from two villages (one in rural Shanxi, northern China and another in rural Guizhou, southern China) with/without space heating during a winter period. Size distributions of particles in indoor and outdoor air, as well as inhaled air, were evaluated, and the difference among different household fuels was discussed. Personal daily exposure was assessed by using portable carries samplers, and also compared to the calculated time-weighted average exposure based on air concentrations measured using stationary samplers and time spent indoor and outdoor.

## 2. Method

### 2.1. Field sites

The present study selected two villages (see Fig. 1): Taigu, Shanxi province located in the northern China and Anshun, Guizhou province located in the southern China. In rural Taigu, most houses are one-floor buildings, and usually have one kitchen, one living room and one or more bedrooms. In most houses, these rooms are connected with interior doors. The average ambient temperature in winter was approximately −12 °C. Similar to many other rural areas in the northern China, there is no central heating, and all residents rely on traditional solid fuels for heating during cold winter. Exterior door and windows are usually closed in cold winter when room heating occurred in indoor. A preliminary survey found that most residents are local farmers, and solid fuels are commonly used for cooking and heating. Honeycomb briquettes and wood are the two most widely used cooking fuels, while raw coal and peat are the two main heating fuels. Thus, considering the different fuels used for cooking and heating demands, four combinations existed in Taigu, that is, honeycomb briquette for cooking and coal for heating (Bri.+C), honeycomb briquette for cooking and peat for heating (Bri.+P), wood for cooking and coal for heating (Wood + C), and wood for cooking and peat for heating (Wood + P).

Anshun has a population of approximately 2.0 million. The average ambient temperature in winter was approximately 4.3 °C, which was much higher than that in Taigu. As opposed to homes in the northern China, the need for space heating in the southern area is not as strong, and thus space heating is not very common. Most houses in rural Anshun have 3–4 rooms including one kitchen, one living room and 1–2 bedrooms. Kitchen is usually connected to the living room. Most residents in rural Anshun are local farmers. Wood

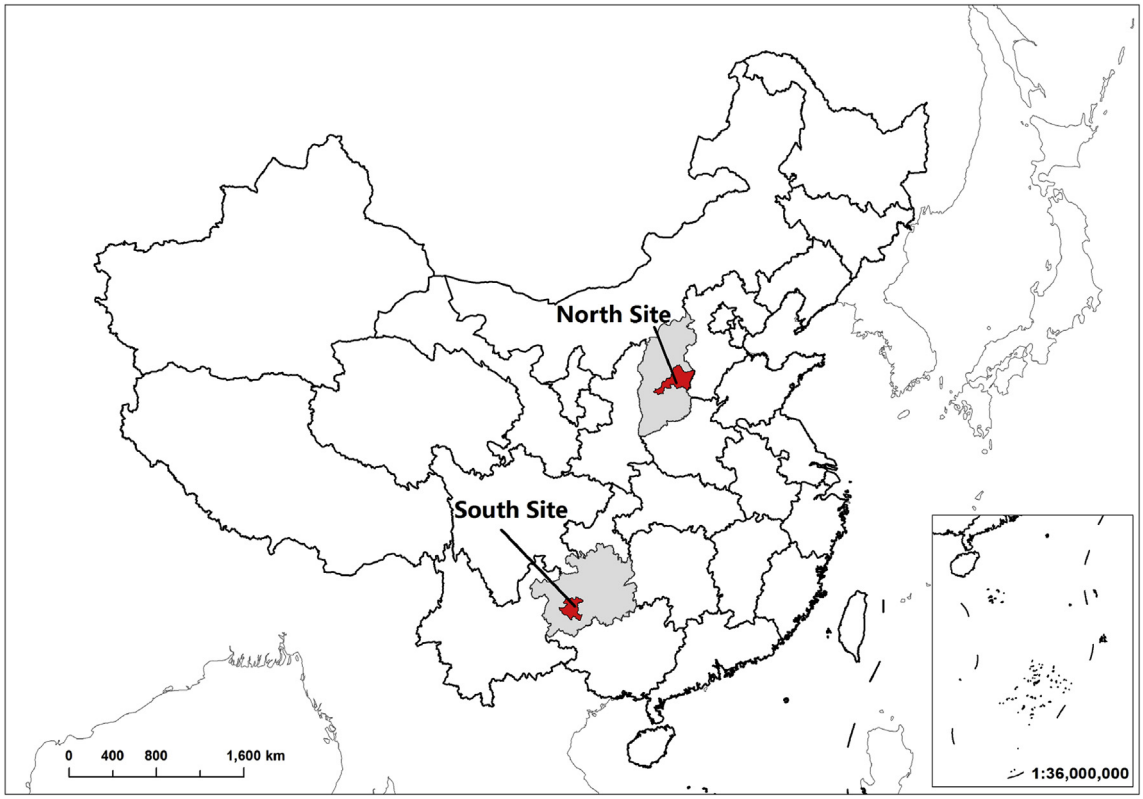


**Fig. 1.** Location of the two field study sites in the northern and southern China, respectively.