Science of the Total Environment 884 (2023) 163749

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Impacts of household $PM_{2.5}$ pollution on blood pressure of rural residents: Implication for clean energy transition

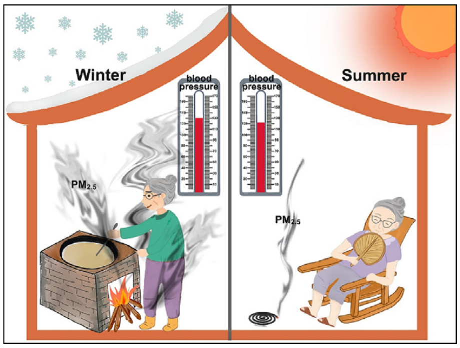
Jinze Wang [b,c], Wei Du [a,c,*], Yali Lei [c], Wenyan Duan [a], Kang Mao [d], Zhenglu Wang [e], Bo Pan [a]

[a] Yunnan Provincial Key Laboratory of Soil Carbon Sequestration and Pollution Control, Faculty of Environmental Science & Engineering, Kunming University of Science & Technology, Kunming 650500, China
[b] Key Laboratory for Earth Surface Processes, College of Urban and Environmental Sciences, Peking University, Beijing 100871, China
[c] Key Laboratory of Geographic Information Science of the Ministry of Education, School of Geographic Sciences, East China Normal University, Shanghai 200241, China
[d] State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, China
[e] West China School of Public Health and West China Fourth Hospital, Sichuan University, Chengdu 610041, China

HIGHLIGHTS

- Seasonal $PM_{2.5}$ exposure and blood pressure (BP) were measured in field.
- Mosquito coil use was associated with 20.9 μg/m^3 higher $PM_{2.5}$ exposure.
- The clean fuel transition is benefit to lower $PM_{2.5}$ exposure and BP.
- Decreased BP in summer is owing to lower $PM_{2.5}$ exposure and higher temperature.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Hai Guo

Keywords:
$PM_{2.5}$ exposure
Blood pressure
Seasonal variations
Rural residents

ABSTRACT

High blood pressure associated with $PM_{2.5}$ exposure is of great concern, especially for rural residents exposed to high $PM_{2.5}$ levels. However, the impact of short-term exposure to high $PM_{2.5}$ on blood pressure (BP) has not been well elucidated. Thus, this study aims to focus on the association between short-term $PM_{2.5}$ exposure with BP of rural residents and its variation between summer and winter. Our results showed that the summertime $PM_{2.5}$ exposure concentration was 49.3 ± 20.6 μg/m^3, among which, mosquito coil users had 1.5-folds higher $PM_{2.5}$ exposure than non-mosquito coil users (63.6 ± 21.7 vs 43.0 ± 16.7 μg/m^3, $p < 0.05$). The mean systolic and diastolic BP (SBP and DBP, respectively) of rural participants were 122 ± 18.2 and 76.2 ± 11.2 mmHg in summer, respectively. The $PM_{2.5}$ exposure, SBP, and DBP in summer were 70.7 μg/m^3, 9.0 mmHg, and 2.8 mmHg lower than that in winter, respectively. Furthermore, the correlation between $PM_{2.5}$ exposure and SBP was stronger in winter than that in summer, possibly due to higher $PM_{2.5}$ exposure levels in winter. The transition of household energy from solid fuels in winter to clean fuels in summer would be benefit to the decline of $PM_{2.5}$ exposure as well as BP. Results from this study suggested that the reduction of $PM_{2.5}$ exposure would have positive effect on human health.

---

[*] Corresponding author at: Yunnan Provincial Key Laboratory of Soil Carbon Sequestration and Pollution Control, Faculty of Environmental Science & Engineering, Kunming University of Science & Technology, Kunming 650500, China.
E-mail address: wdu@geo.ecnu.edu.cn (W. Du).

http://dx.doi.org/10.1016/j.scitotenv.2023.163749
Received 16 March 2023; Received in revised form 12 April 2023; Accepted 22 April 2023
Available online 27 April 2023

1. Introduction

Solid fuels are extensively used in rural China, accounting for 41.1 % and 84.9 % of residential cooking and heating fuels, respectively (Tao et al., 2018). The inefficient combustion of solid fuels in rural households can yield large quantities of air pollutants (e.g., $PM_{2.5}$, particles with aerodynamic diameter equal to or <2.5 μm), resulting in serious household air pollution and threatening human health (Li et al., 2018; Huang et al., 2022; Wu et al., 2022a). For example, Du et al. (2018) reported that $PM_{2.5}$ concentrations monitored in rural kitchen and bedroom associated with solid fuel combustion ranged from 62 to 1944 $\mu g/m^3$ and from 63 to 2334 $\mu g/m^3$, respectively. As a result, rural residents had relatively high $PM_{2.5}$ exposure levels, which were in the range of 30 to 600 $\mu g/m^3$ and were generally calculated by time-weighted method. Yun et al. (2020) estimated that $PM_{2.5}$ emission from rural residential sector was 2.4 terrogram (Tg) in 2014, which accounted for 20.9 % of total primary $PM_{2.5}$ emission and caused 6.4 million premature deaths in China.

High blood pressure (BP) is a strong risk factor for cardiovascular disease, stroke, and coronary artery disease (Warren et al., 2017; GBD 2019 Risk Factors Collaborators, 2020), resulting in 10.8 million premature deaths globally in 2019, accounting for 19.2 % of the total deaths (GBD 2019 Risk Factors Collaborators, 2020). The influences of $PM_{2.5}$ exposure on BP have been revealed by both animal and epidemiological studies (Hoffmann et al., 2012; Liang et al., 2014; Chang et al., 2015). Some previous studies have confirmed that $PM_{2.5}$ exposure is associated with the increase of BP (Chang et al., 2015; Lin et al., 2017; Du et al., 2021), possibly due to sympathetic nervous system activation and vascular dysfunction attributable to $PM_{2.5}$ exposure (Brook et al., 2010). However, some inconsistent results that $PM_{2.5}$ exposure has minor influence on BP have also been reported (Smargiassi et al., 2014; Chu et al., 2018; Hu et al., 2018; Ren et al., 2019), resulting in large uncertainty in association between $PM_{2.5}$ exposure and BP, which calls for more evaluation to address this issue.

In previous studies, ambient $PM_{2.5}$ data is widely adopted to investigate the short-term health effects associated with $PM_{2.5}$ exposure (Xu et al., 2020; Hu et al., 2022; Wu et al., 2022b). However, ambient $PM_{2.5}$ concentration can hardly represent personal $PM_{2.5}$ exposure since people usually spend most of their time indoors, where air pollution generally differs largely from ambient air pollution (Ren et al., 2019; Chan et al., 2021; Li et al., 2021). To date, there are few studies on short-term personal $PM_{2.5}$ exposure and its association between BP, and most of which are conducted in urban area where $PM_{2.5}$ exposure is relatively low (Chan et al., 2021; Van Nunen et al., 2021; Oh et al., 2022). Even less studies have focused on the association between short-term $PM_{2.5}$ exposure and BP in highly polluted rural areas (Chen et al., 2020; Du et al., 2021). Available studies have revealed the important impact of $PM_{2.5}$ exposure on BP of rural residents. For example, Chen et al. (2020) reported that $PM_{2.5}$ exposure of rural residents was significantly positively correlated with their systolic blood pressure (SBP) in Shanxi in winter, with per 10 $\mu g/m^3$ increase of $PM_{2.5}$ exposure led to 0.36 mmHg incremental SBP. In addition, personal $PM_{2.5}$ exposure can vary substantially between seasons due to large differences in seasonal household $PM_{2.5}$ pollution (Huang et al., 2022), which may affect its impact on BP (Baumgartner et al., 2011); however, this has not been well elucidated. Therefore, special attention should be paid on the association between short-term high $PM_{2.5}$ exposure with BP of rural residents as well as its seasonal variation.

In this study, field campaigns were conducted to measure personal $PM_{2.5}$ exposure and BP of rural residents in Hunan Province, southern China, in winter and summer. Personal $PM_{2.5}$ exposure and its relationship with BP during wintertime were discussed in our previous study (Du et al., 2021), in which we emphasized the impact of the Chinese Spring Festival on indoor $PM_{2.5}$ pollution and BP. The main objectives of this study are 1) to investigate the $PM_{2.5}$ exposure and BP of rural residents in summer; 2) to explore the impact of various influencing factors on summertime $PM_{2.5}$ exposure and BP; and 3) to insight into seasonal differences in $PM_{2.5}$ exposure, BP, and their relationships.

2. Materials and methods

2.1. Sampling site and information collected

The field sampling sites were located in rural Taojiang county, Hunan Province, southern China. In Taojiang, a humid subtropical monsoon climate is often observed. Annual temperature here is 16.8 °C, with higher temperatures of 22 °C to 33 °C in summer and lower temperatures of −4 °C to 5 °C in winter (HNBS, 2021). The land use types of the sampling sites are major of farmland, forest, and residential land. The summertime campaign was conducted during 20 to 27, July 2020, while was during 12 to 20, January 2020 for wintertime campaign. The summertime campaign was a revisited study of the wintertime campaign.

Previous studies have revealed that personal exposure is determined by various influencing factors including but not limited to indoor and outdoor pollutant concentrations, ventilation, kitchen configuration, etc., among which, pollutant concentrations and ventilation condition are frequently studied (Hodas et al., 2016; Huang et al., 2017; Du et al., 2018). Therefore, in this study, factors that affected air pollution levels including fuel type, mosquito coil use, and family population, and factors that affected ventilation condition including kitchen ventilation, the connection of kitchen and living room, and window opening hours were selected. As for the influencing factors to BP, in addition to $PM_{2.5}$ exposure, other frequently studied influencing factors were also considered including gender, smoking activity, body weight index (BMI), education, and age (Baumgartner et al., 2011; Pitchika et al., 2017; Wang et al., 2019). Face-to-face questionnaires were used to record the above information (Table S1).

2.2. $PM_{2.5}$ exposure and BP measurement

Residents volunteered to participate in the campaign were randomly selected, and 98 rural residents were enrolled in summer campaign. Optical $PM_{2.5}$ samplers with 5-second resolution (Zefan Technol, China) were put in kitchen and living room (1.5 m height, 1.0 m away from stoves and walls), as well as outdoor (central of the yard) of rural homes to record real-time $PM_{2.5}$ concentrations. All $PM_{2.5}$ samplers were calibrated using Synchronized Hybrid Ambient Real-time Particulate [SHARP] 5030 monitor (Thermo Scientific, Waltham, MA, USA) for at least 15 days prior to field sampling.

In this study, 24 h sampling was conducted to monitor household $PM_{2.5}$ concentrations. After sampling, personal $PM_{2.5}$ exposure concentration was calculated based on time-weighted method by combining $PM_{2.5}$ concentrations in different microenvironments with the corresponding time that residents spent in these microenvironments (see Eq. (1)).

$$PM_{2.5}\ \text{exposure} = \sum_{i=1}^{n=3} Ci \times Ti/1440 \tag{1}$$

where Ci represents the daily averaged $PM_{2.5}$ concentrations in microenvironment i, and Ti is the time that residents spend in microenvironment i (minutes). 1440 is the total time in a day (minutes).

The BP measurement was conducted at the same time with household $PM_{2.5}$ measurement for each resident. Omron upper arm electronic BP monitors (model HEM-759-E; Omron Healthcare, Japan) were used to measure BP, including SBP and diastolic blood pressure (DBP), following previous methods (Yin et al., 2017; Chen et al., 2020). Three repeated measurements were conducted within 10 min in the right arm of residents who had finished meals for over 1 h and rested for over 10 min, and the average values were calculated as the final BP (Meier et al., 2014; Yin et al., 2017).

2.3. Data analysis

The generalized linear model (GLM) was applied to explore the relationships between various influencing factors and $PM_{2.5}$ exposure as well as BP. The formulas were shown as below:

$$PM_{2.5}\ \text{exposurei} = \beta1x1i + \beta2x2i + \beta3x3i + \beta4x4i + \beta5x5i + \beta6x6i \tag{2}$$

where x1, x2, x3, x4, x5, and x6 represent family population size, cooking fuel, mosquito coil combustion, the connection of kitchen and living room, kitchen ventilation, and widow opening hour, respectively.

$$BPi = \beta 1y1i + \beta 2y2i + \beta 3y3i + \beta 4y4i + \beta 5y5i + \beta 6y6i \tag{3}$$

where y1, y2, y3, y4, y5, and y6 represent $PM_{2.5}$ exposure, smoking activity, gender, BMI, age, and education, respectively.

Notably, the impacts of these influencing factors on $PM_{2.5}$ exposure and BP in winter were discussed in our previous study (Du et al., 2021). Furthermore, the contribution of each influencing factor to total variances of $PM_{2.5}$ exposure and BP were estimated by dominance analysis. R Studio (version 3.4.0) was used to perform the GLM and dominance analysis. The Kolmogorov-Smirnov Z test and one-way ANOVA were adopted to test the significances of influencing factors on different groups according to data distribution in SPSS 21.0 (IBM Corp., NY, USA), the statistical significance level of 0.05 was adopted.

3. Results and discussion

3.1. Characteristics of rural participants

In summertime campaign, the majority of the participants were female, which accounted for 58.0 % of total. The average age of participants was 61.7 ± 13.7, with 34.7 % of the participants were in the range of 50 to 60 years old. Most of the participants had education experience, and elementary education was the predominate education form (40.8 %), following by junior and senior high school (23.5 % and 19.4 %, respectively). The major population size of rural households investigated in this study was two to three (71.2 %), and 6.1 % of total families had >5 people. The BMI of enrolled residents was 22.3 ± 3.0 kg/m^2 with 25.5 % of participants were overweight (≥24 kg/m^2 in Chinese criteria (Zhou, 2002)). Clean fuels including liquid petroleum gas (LPG) and electricity were the major residential cooking energies with a usage proportion of 79.0 %, while solid fuels including fuel wood and coal accounted for 21.0 %.

As shown in Fig. 1a, the daily averaged $PM_{2.5}$ exposure of rural participants in summer was 49.3 ± 20.6 $\mu g/m^3$, and almost all the rural participants (99.0 %) failed to meet the $PM_{2.5}$ air quality guideline level suggested by World Health Organization (WHO, 2021), indicating high $PM_{2.5}$ exposure risk of rural residents. The mean SBP was 122 ± 18.2 mmHg with 12.2 % high-normal BP (prehypertension, see Fig. 1b), and the mean DBP was 76.2 ± 11.2 mmHg with 25.5 % high-normal BP (Fig. 1c). Furthermore, 18.4 % of participants had hypertension (SBP ≥ 140 mmHg and/or DBP ≥ 90 mmHg).

3.2. Influencing factors

3.2.1. Variations in $PM_{2.5}$ exposure under different influencing factors

As shown in Fig. 2, the $PM_{2.5}$ exposure of residents using mosquito coil was 63.6 ± 21.7 $\mu g/m^3$, significantly higher than those did not use (43.0 ± 16.7 $\mu g/m^3$, $p < 0.05$, Table S2). Previous studies have revealed that mosquito coil combustion can elevate indoor $PM_{2.5}$ concentrations due to its high $PM_{2.5}$ emissions as well as long combustion time (Sinaga et al., 2020; Huang et al., 2022). Results here indicated that serious health threat of mosquito coil combustion and called for more attention on the control of mosquito coil use. In previous studies, the importance of fuel type on personal $PM_{2.5}$ exposure has been often proposed (Gao et al., 2009; Du et al., 2017; Deepthi et al., 2019). Of these studies, the use of clean fuels, such as electricity and LPG, could alleviate household $PM_{2.5}$ pollution and reduce personal $PM_{2.5}$ exposure compared with traditional solid fuels. However, in this study, no significant difference in $PM_{2.5}$ exposure was observed for residents using fuel wood, electricity, LPG, and coal for cooking, which were 42.1 ± 9.8, 46.6 ± 19.7, 54.0 ± 37.8 and 58.7 ± 22.1 $\mu g/m^3$, respectively ($p > 0.05$, Table S2). In summertime campaign, residents spent only 1.7 h in the kitchen, resulting in relatively small influence of cooking fuel on $PM_{2.5}$ exposure. Furthermore, mosquito coil use was recorded in 35.1 % of clean fuel users, higher than that of solid fuel users (14.3 %), indicating that mosquito coil was more prevail in clean fuel users. This further reduced the influence of fuel type on $PM_{2.5}$ exposure and resulted in relatively high $PM_{2.5}$ exposure for clean fuel users. Other influencing factors investigated in this study including household population, the connection of kitchen and living room, kitchen ventilation, and window opening hour had minor impacts on $PM_{2.5}$ exposures of rural residents in summer, as seen in Fig. 2 and Table S2 ($p > 0.05$).

Results from relative contribution analysis showed that window opening hour contributed mostly to the variance of $PM_{2.5}$ exposure in summer (45 %), indicating the crucial influence of ventilation condition on $PM_{2.5}$ exposure. Mosquito coil combustion contributed 29 % to total $PM_{2.5}$ exposure variance, highlighting the importance of mosquito coil use on personal $PM_{2.5}$ exposure again.

3.2.2. Variations in BP under various influencing factors

Results from the GLM showed that SBP of rural participants in summer were positively correlated with age and BMI ($p < 0.05$) (Fig. 3 and Table S3), indicating that elderly and overweight residents might suffer from higher risk of high BP, which was consisted with previous studies (Song et al., 2021; Ye et al., 2022). The higher prevalence of pre-existing diseases for elderly people and the higher deposition rate of $PM_{2.5}$ for overweight people made them more susceptible to $PM_{2.5}$ exposure than others

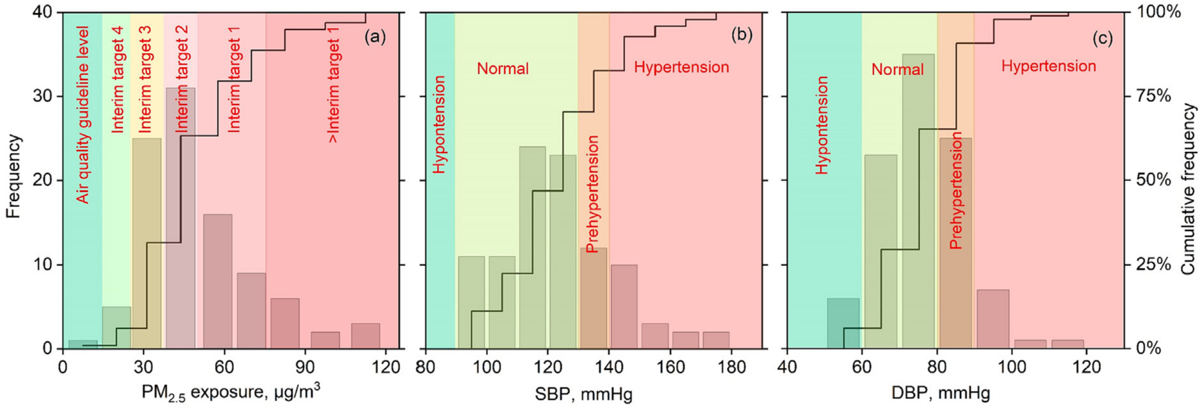


Fig. 1. The frequency distributions (histograms) and cumulative frequencies (black lines) of daily averages of $PM_{2.5}$ exposure (a) and SBP (b) as well as DBP (c) of all enrolled residents in summer campaign, respectively. The air quality guideline level and interim targets of short-term exposure to $PM_{2.5}$ in Fig. 1a is suggested by World Health Organization (WHO, 2021).

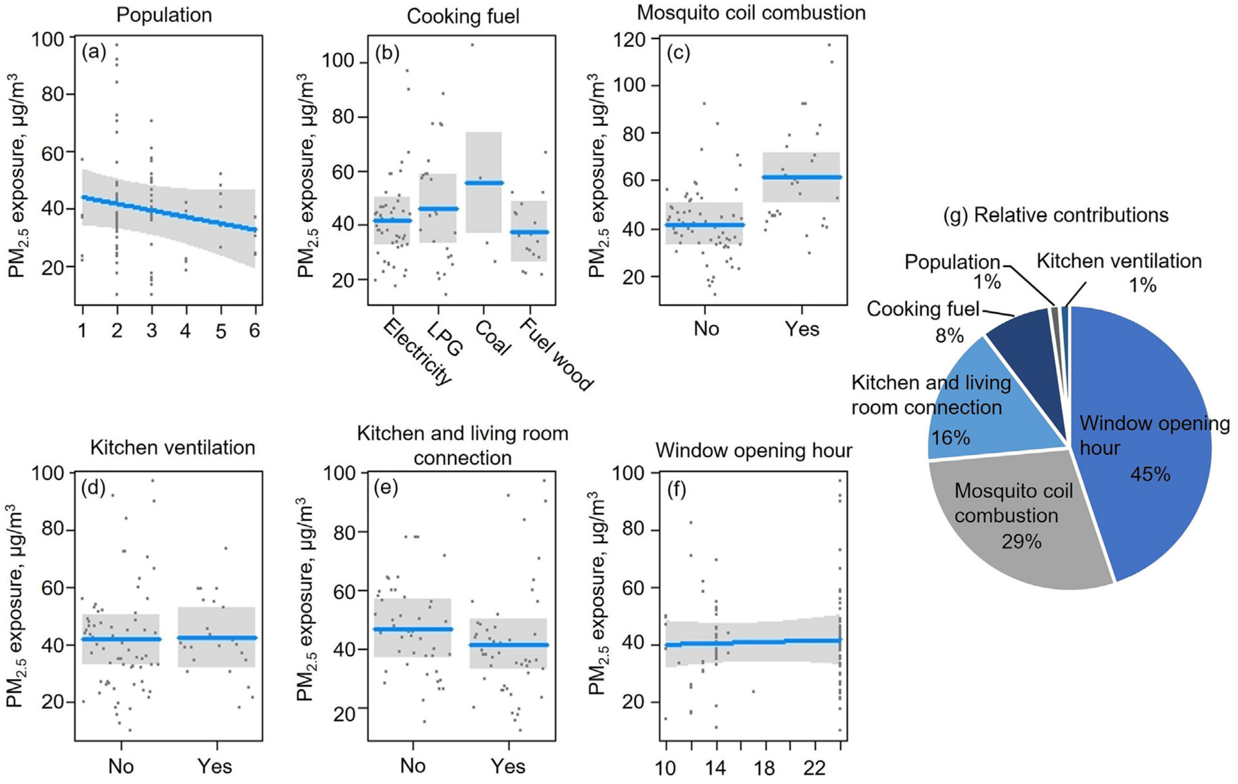


Fig. 2. The partial effects of investigated influencing factors on $PM_{2.5}$ exposure (a–f), and (g) their proportions of the total variance of $PM_{2.5}$ exposure in summer based on the GLM together with the dominance analysis.

(Song et al., 2021). Positive correlations were also observed between $PM_{2.5}$ exposure and SBP as well as DBP, but the correlation was not significant ($p > 0.05$). DBP of rural participants varied slightly under different influencing factors in summer (Fig. S1 and Table S4). Similar results were also reported in previous studies (Auchincloss et al., 2008; Zhao et al., 2015; Pangaribuan et al., 2019).

As shown in Fig. 3g, age was the predominant influencing factor which contributed 50 % to the variance of SBP in summer, following by BMI with a contribution of 28 %. As for the variance of DBP, the major contributors were BMI and gender, which accounted for 28 % and 27 % of total variance, respectively. $PM_{2.5}$ exposure contributed 9 % to SBP variance, which was higher than its contribution to DBP variance (4 %), suggesting that $PM_{2.5}$ exposure had larger impact on SBP than DBP, which was consistent with our results in winter campaign (Du et al., 2021).

3.3. Difference between summer and winter

3.3.1. $PM_{2.5}$ exposure

The summertime $PM_{2.5}$ exposure of rural participants was 49.3 ± 20.6 μg/m^3, 59 % lower than that in winter (120 ± 49 μg/m^3) ($p < 0.05$), which was attributable to lower indoor and outdoor $PM_{2.5}$ pollution in summer (Huang et al., 2022). In our wintertime study, fuel type was a significant influencing factor to $PM_{2.5}$ exposure (Du et al., 2021), while mosquito coil combustion significantly influenced summertime $PM_{2.5}$ exposure. However, previous studies always focused on the impact of fuel type on $PM_{2.5}$ exposure, while ignoring the influence of mosquito coil use (Feng et al., 2021). In this study, the influences of household fuel transition together with mosquito coil use on seasonal variations in $PM_{2.5}$ exposure were compared (Fig. 4). As shown in Fig. 4, the fuel transition from solid fuels in winter to clean fuels in summer (S-C group) and from mixed fuels (both solid fuels and clean fuels) to clean fuels (M-C group) had relatively higher seasonal differences in $PM_{2.5}$ exposure (defined as the winter $PM_{2.5}$ exposure minus summer $PM_{2.5}$ exposure of the same residents group) than other groups, which were 70.8 ± 24.1 and 63.5 ± 46.2 μg/m^3, respectively, indicating that clean fuel transition was benefit to decrease $PM_{2.5}$ exposure. Previous studies have also revealed that clean transition of household energy has considerable benefits not only for pollutant emission reduction but also for human health protection (Sun et al., 2019, 2022). For example, Sun et al. (2019) reported that the annual emission reduction of 15,000 ton for total volatile organic compounds (TVOCs) in Guanzhong Plain could be achieved by the adoption of clean coal techniques for residential heating. Owing to coal-to-gas/electricity project in rural China, the risks of chronic lung diseases and asthma decreased by 1.4 % and 1.3 %, respectively (Wen et al., 2023).

The seasonal differences in $PM_{2.5}$ exposure for S-S group (using solid fuels both in winter and summer) were 57.6 ± 19.2 μg/m^3, higher than that for C-C group (using clean fuels both in winter and summer) (37.5 ± 21.4 μg/m^3), which was because the solid fuel consumption in summer was much lower than that in winter (5.6 vs 20.4 kg per household) (Huang et al., 2022). Furthermore, for rural participants undergoing the same seasonal fuel transition, mosquito coil users associated with 24.9 μg/m^3 lower seasonal differences in $PM_{2.5}$ exposure than those did not. This was due to the combustion of mosquito coil increased $PM_{2.5}$ exposure in summer and then reduced seasonal differences in $PM_{2.5}$ exposure. Therefore, the influence of mosquito coil combustion on $PM_{2.5}$ exposure should be paid special attention.

3.3.2. BP

The SBP and DBP in summer were 9.0 and 2.8 mmHg lower than in winter (SBP: 131 ± 18 mmHg, DBP: 79 ± 12 mmHg, $p < 0.05$), respectively. Furthermore, the proportions of high BP and high-normal BP for SBP in winter were 28.9 % and 24.5 %, respectively. As for wintertime DBP, high BP and high-normal BP accounted for 16.7 % and 28.1 % of total, respectively. This indicated that residents had not only higher BP levels, but also higher proportions of hypertension in winter than in summer. The influences of household fuel transition and mosquito coil use on seasonal differences in BP were further explored. As shown in Fig. S2, significant seasonal differences in SBP were observed for different seasonal household

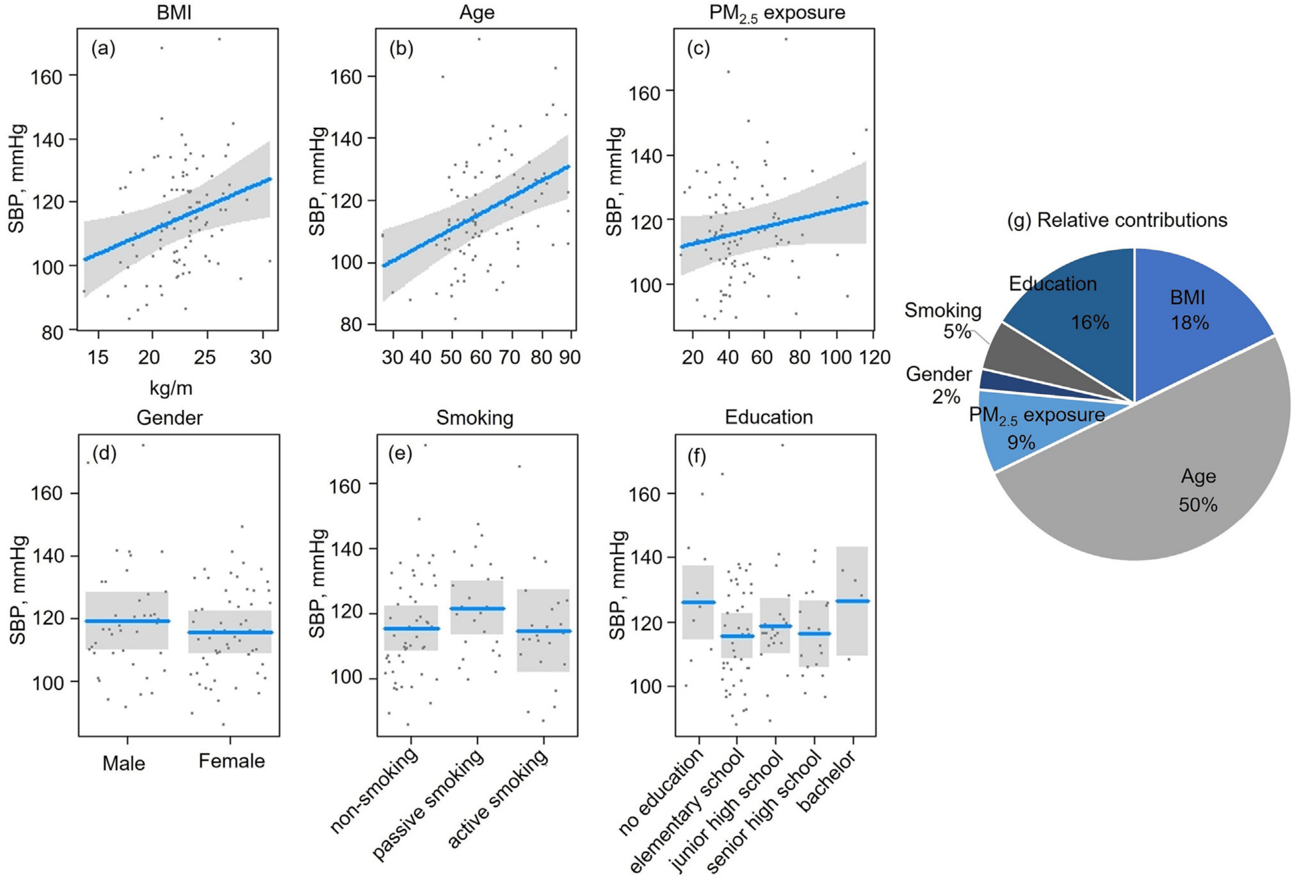


Fig. 3. The partial effects of investigated influencing factors on SBP (a-f), and their proportions of the total variance of SBP (g) in summer according to the GLM together with the dominance analysis.

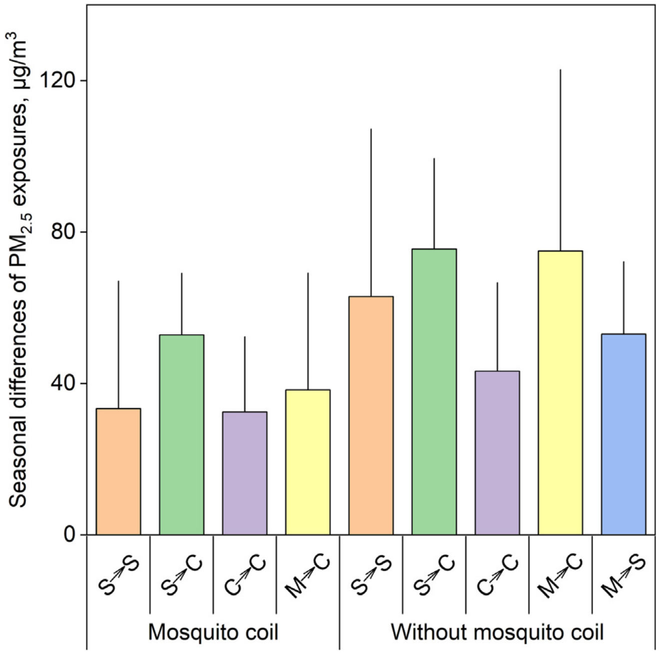


Fig. 4. The influences of household fuel transition couple with mosquito coil use on the seasonal differences in $PM_{2.5}$ exposure. The letters of S, C, and M in the figure represent residents using solid fuels, clean fuels, and mixed fuels, respectively, the arrow between letters represents the fuel transition from winter to summer.

fuel transition groups ($p < 0.05$), while the seasonal differences in DBP were relatively smaller ($p > 0.05$). The seasonal differences of SBP and DBP were relatively larger in S-C group compared with other groups (Fig. S2), indicating that the transition to clean energy would be benefit to lower BP. As for the C-C group, their BP changed relatively smaller than other groups. For residents undergoing the same seasonal household fuel transition, mosquito coil users had 5.2 and 0.5 mmHg lower seasonal differences in SBP and DBP than those did not, respectively, possibly because the elevated $PM_{2.5}$ exposure caused by mosquito coil combustion would increase BP.

3.3.3. Factors influencing BP variation between summer and winter

In our wintertime study, $PM_{2.5}$ exposure was significantly associated with SBP ($p < 0.05$), but the association between $PM_{2.5}$ exposure and DBP were not significant ($p > 0.05$) (Du et al., 2021); this was in line with previous studies (Auchincloss et al., 2008; Zhao et al., 2015; Liu et al., 2017; Chen et al., 2020). For example, Zhao et al. (2015) reported that $PM_{2.5}$ exposure was positively associated with SBP but not with DBP, with an interquartile range (48 $\mu g/m^3$) incremental $PM_{2.5}$ exposure associated with 2.71 mmHg higher SBP. Whereas in this summertime study, no significant correlations were found between $PM_{2.5}$ exposure and SBP as well as DBP, which was also consistent with some previous studies (Madsen and Nafstad, 2006; Smargiassi et al., 2014; Corlin et al., 2018; Hu et al., 2018; Chi et al., 2019). For example, Chi et al. (2019) reported that $PM_{2.5}$ exposure had no significant influences neither on SBP or DBP for elderly people in summer, possibly explained by the variations in $PM_{2.5}$ levels and components, population characteristics (ages, diet, mental health, and lifestyle), as well as sampling methods (Zhao et al., 2015; Liu et al., 2017).

The seasonal variations in BP may partly be attributed to the changes in seasonal $PM_{2.5}$ concentrations. Previous studies have suggested that $PM_{2.5}$ exposure level plays an important role on BP regulation. For example, Shan et al. (2014) reported that 4.6 mmHg higher SBP for rural females in high $PM_{2.5}$ exposure group (101 ± 37 μg/m^3) than those in low $PM_{2.5}$ exposure group (39 ± 11 μg/m^3). In another study conducted by McCracken et al. (2007), the $PM_{2.5}$ exposures of rural females deceased 38 % after the promotion of advanced low-polluting stoves (from 273 ± 317 to 174 ± 193 μg/m^3), and resulted in 3.1 and 1.9 mmHg decline in their SBP and DBP, respectively. Similarly, significant association between $PM_{2.5}$ exposure and BP for young adults was only found in winter and spring, but not in summer and fall due to relatively higher $PM_{2.5}$ exposure in former seasons (Ye et al., 2022). Feng et al. (2021) compared the BP of rural residents in Fenwei plain between winter and summer, results showed that SBP and DBP in winter were 1.6 and 1.1 times higher than that in summer, which was possibly due to severe $PM_{2.5}$ pollution associated with heavy solid fuel combustion in winter. The fluctuations in air pollutant concentrations would affect cardiac output and peripheral vascular resistance and finally change BP, resulting in higher BP level in winter than that in summer (Chiarelli et al., 2011). Zhang et al. (2020) previously reported that seasonal variations in cardiac function caused by $PM_{2.5}$ exposure were attributed to different air pollutant concentrations and more severe cardiac dysfunction in winter. In addition, high $PM_{2.5}$ exposure may have stronger impact on BP. For example, Song et al. (2021) reported that hypertension prevalence and SBP strongly responded to high $PM_{2.5}$ exposure (over 50 μg/m^3), which was similar with our study, highlighting the necessity of health impact evaluation for people exposed to high $PM_{2.5}$ levels.

In addition to $PM_{2.5}$ exposure, differences in temperature may also contribute to seasonal variations in BP (Madsen and Nafstad, 2006; Linares and Diaz, 2008; Chiarelli et al., 2011; Lewington et al., 2012). In this study, the average time-weighted temperature in summer was 30.3 ± 2.6 °C, significantly higher than that in winter (10.5 ± 2.8 °C, $p < 0.05$). Significant negative correlations were found between time-weighted temperature and SBP as well as DBP ($p < 0.05$), which was consistent with previous studies. For example, Goyal et al. (2018) reported negative association between BP and temperature, with each 10 °C increment of temperature, the SBP and DBP would decrease 3.9 and 2.7 mmHg, respectively. Similarly, results from Lewington et al. (2012) showed that per 10 °C decrease in temperature was associated with 5.7 and 2.0 mmHg increases in SBP and DBP, respectively. Epidemiological study also revealed that home temperature was negatively associated with hypertension rate, with a 1 °C increment of temperature associated with 0.98 (95 % confidence interval: 0.96–0.99) lower odd ratio of hypertension (Modesti et al., 2013). Previous studies have indicated that low temperatures may increase sympathetic activity and aldosterone levels, as well as reduce sweating, and thus lead to increased BP. While the increase of temperatures may lead to cutaneous vasodilatation and increased sweating, as a consequent, the BP decrease (Rosenthal, 2004; Miersch et al., 2013).

4. Implication and limitation

High BP is a leading health risk for human. Previous studies have suggested that short-term exposure to $PM_{2.5}$ may increase the risk of hypertension (Cai et al., 2016; Oh et al., 2022). However, there are few studies on the association between short-term high $PM_{2.5}$ exposure, which is common for rural residents, with BP, and even fewer studies on the seasonal variations of their relationship. In this study, field measurements were conducted in rural China to investigate seasonal variations in personal $PM_{2.5}$ exposure and BP as well as their relationships. It was found that $PM_{2.5}$ exposure of rural residents decreased significantly in summer due to clean energy transition. Lower BP and weaker correlation between $PM_{2.5}$ exposure and BP were also found in summer than in winter, indicating that the decrease of $PM_{2.5}$ exposure was beneficial to the decline of BP of rural residents. Results from this study provide new perspectives into short-term impact of high $PM_{2.5}$ exposure on BP and its seasonal variations, as well as the potential health benefits of clean fuel transition of rural household energy.

There were several limitations that should be stated in this study. The summer campaign was a revisit study. However, due to some rural residents went out for work or travel during summer campaign, they were failed to be revisited. This resulted in relatively small sample size of summer campaign which may affect the accuracy of statistical results to some extent. Although twelve influencing factors to personal $PM_{2.5}$ exposure and BP were investigated in this study, the information on some factors that might affect personal $PM_{2.5}$ exposure and/or blood pressure such as air conditioner use and household income were not collected. In future, more factors that may affect personal $PM_{2.5}$ exposure and/or blood pressure should be taken into consideration.

5. Conclusion

The association between $PM_{2.5}$ exposure and BP has been revealed by previous studies. However, studies are limited regarding the impact of short-term high $PM_{2.5}$ exposure on BP and its seasonal variation. In this study, seasonal variations in $PM_{2.5}$ exposure and BP as well as their relationships were explored based on field measurements in rural areas. Results showed that $PM_{2.5}$ exposure of rural participants in summer was 59 % lower than that in winter. In addition, summertime SBP and DBP were 9.0 and 2.8 mmHg lower than that in winter, respectively. Mosquito coil users had 1.5 times higher summertime $PM_{2.5}$ exposure than non-mosquito coil users. $PM_{2.5}$ exposure was positively associated with BP, and such association was stronger in winter than in summer. Household fuel transition from solid fuels in winter to clean fuels in summer was benefit to reduce $PM_{2.5}$ exposure as well as BP, while mosquito coil combustion would be negative on the reduction of BP and $PM_{2.5}$ exposure. Apart from the lower $PM_{2.5}$ exposure in summer, higher temperature could also lead to the decrease of BP.

CRediT authorship contribution statement

Jinze Wang: Investigation, Writing - the original draft, Writing - Reviewing and Editing; **Wei Du**: Funding Acquisition, Supervision, Investigation, Conceptualization, Writing - the original draft, Writing - Reviewing and Editing; **Yali Lei**, **Wenyan Duan**, **Kang Mao**, **Zhenglu Wang**, and **Bo Pan**: Writing - Reviewing and Editing.

Data availability

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We'd like to thank the rural residents who took part in this sampling and Prof. Yuanchen Chen for his valuable suggestions. This research was funded by National Natural Science Foundation of China (42107107), Yunnan Fundamental Research Projects, grant number 202201AT070665, and Yunnan Major Scientific and Technological Projects, grant number 202202AG050019.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2023.163749.

References

Auchincloss, A.H., AVD, Roux, Dvonch, J.T., Brown, P.L., Barr, R.G., Davigius, M.L., Goff, D.C., Kaufman, J.D., O'Neill, M.S., 2008. Associations between recent exposure to ambient fine particulate matter and blood pressure in the Multi-Ethnic Study of Atherosclerosis (MESA). Environ Health Persp 116, 486–491.

Baumgartner, J., Schauer, J.J., Ezzati, M., Lu, L., Cheng, C., Patz, J.A., Bautista, L.E., 2011. Indoor air pollution and blood pressure in adult women living in rural China. Environ. Health Perspect. 119, 1390–1395.

Brook, R.D., Rajagopalan, S., Pope, C.A., Brook, J.R., Bhatnagar, A., Diez-Roux, A.V., Holguin, F., Hong, Y.L., Luepker, R.V., Mittleman, M.A., Peters, A., Siscovick, D., Smith, S.C., Whitsel, L., Kaufman, J.D., AHaC, Epidemiol, CKC, Dis, CNPA, Metab, 2010. Particulate matter air pollution and cardiovascular disease an update to the scientific statement from the American Heart Association. Circulation 121, 2331–2378.

Cai, Y.Y., Zhang, B., Ke, W.X., Feng, B.X., Lin, H.L., Xiao, J.P., Zeng, W.L., Li, X., Tao, J., Yang, Z.Y., Ma, W.J., Liu, T., 2016. Associations of short-term and long-term exposure to ambient air pollutants with hypertension a systematic review and meta-analysis. Hypertension 68 (1), 62–70.

Chan, K.H., Xia, X., Ho, K.F., Guo, Y., Kurmi, O.P., Du, H.D., Bennett, D.A., Bian, Z., Kan, H.D., Mcdonnell, J., Schmidt, D., Kerosi, R., Li, L.M., Lam, K.B.H., Chen, Z.M., C-aC, Grp, 2021. Regional and seasonal variations in household and personal exposures to air pollution in one urban and two rural Chinese communities: a pilot study to collect time-resolved data using static and wearable devices. Environ. Int. 146.

Chang, L.T., Chuang, K.J., Yang, W.T., Wang, V.S., Chuang, H.C., Bao, B.Y., Liu, C.S., Chang, T.Y., 2015. Short-term exposure to noise, fine particulate matter and nitrogen oxides on ambulatory blood pressure: a repeated-measure study. Environ. Res. 140, 634–640.

Chen, Y.C., Fei, J., Sun, Z., Shen, G.F., Du, W., Zang, L., Yang, L.Y., Wang, Y.H., Wu, R.X., Chen, A., Zhao, M.R., 2020. Household air pollution from cooking and heating and its impacts on blood pressure in residents living in rural cave dwellings in loess plateau of China. Environ. Sci. Pollut. Res. 27, 36677–36687.

Chi, R., Chen, C., Li, H.Y., Pan, L., Zhao, B., Deng, F.R., Guo, X.B., 2019. Different health effects of indoor- and outdoor-originated PM2.5 on cardiopulmonary function in COPD patients and healthy elderly adults. Indoor Air 29, 192–201.

Chiarelli, P.S., LaA, Pereira, Saldiva, P.H.D., Ferreira, C., Garcia, M.L.B., Braga, A.L.F., Martins, L.C., 2011. The association between air pollution and blood pressure in traffic controllers in Santo Andre, Sao Paulo, Brazil. Environ. Res. 111, 650–655.

Chu, H.Y., Xin, J.Y., Yuan, Q., Zhang, X., PanW, Zeng X.Y., Chen, Y.Y., Ma, G.X., Ge, Y.Q., Du, M.L., Tong, N., Li, X.B., Zhang, Z.D., Wang, M.L., 2018. Evaluation of vulnerable PM2.5-exposure individuals: a repeated-measure study in an elderly population. Environ. Sci. Pollut. Res. 25, 11833–11840.

Corlin, L., Woodin, M., Hart, J.E., Simon, M.C., Gute, D.M., Stowell, J., Tucker, K.L., Durant, J.L., Brugge, D., 2018. Longitudinal associations of long-term exposure to ultrafine particles with blood pressure and systemic inflammation in Puerto Rican adults. Environ. Health 17.

Deepthi, Y., Nagendra, S.M.S., Gummadi, S.N., 2019. Characteristics of indoor air pollution and estimation of respiratory dosage under varied fuel-type and kitchen-type in the rural areas of Telangana state in India. Sci. Total Environ. 650, 616–625.

Du, W., Li, X.Y., Chen, Y.C., Shen, G.F., 2018. Household air pollution and personal exposure to air pollutants in rural China - a review. Environ. Pollut. 237, 625–638.

Du, W., Shen, G.F., Chen, Y.C., Zhu, X., Zhuo, S.J., Zhong, Q.R., Qi, M., Xue, C.Y., Liu, G.Q., Zeng, E., Xing, B.S., Tao, S., 2017. Comparison of air pollutant emissions and household air quality in rural homes using improved wood and coal stoves. Atmos. Environ. 166, 215–223.

Du, W., Wang, J.Z., Zhang, S.S., Fu, N., Yang, F.Q., Wang, G.H., Wang, Z.L., Mao, K., Shen, G.F., Qi, M., Liu, S.J., Wu, C., Chen, Y.C., 2021. Impacts of chinese spring festival on household PM2.5 pollution and blood pressure of rural residents. Indoor Air 31, 1072–1083.

Feng, R., Xu, H.M., He, K.L., Wang, Z.X., Han, B., Lei, R.H., Ho, K.F., Niu, X.Y., Sun, J., Zhang, B., Liu, P.P., Shen, Z.X., 2021. Effects of domestic solid fuel combustion emissions on the biomarkers of homemakers in rural areas of the Fenwei Plain, China. Ecotox Environ Safe 214.

Gao, X., Yu, Q., Gu, Q., Chen, Y., Ding, K., Zhu, J., Chen, L., 2009. Indoor air pollution from solid biomass fuels combustion in rural agricultural area of Tibet, China. Indoor Air 19, 198–205.

GBD 2019 Risk Factors Collaborators, 2020. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the global burden of disease study 2019. Lancet 396, 1223–1249.

Goyal, A., Aslam, N., Kaur, S., Soni, R.K., Midha, V., Chaudhary, A., Dhaliwal, L.K., Singh, B., Chhabra, S.T., Mohan, B., Anand, I.S., Wander, G.S., 2018. Factors affecting seasonal changes in blood pressure in North India: a population based four-seasons study. Indian Heart J. 70, 360–367.

HNBS, 2021. Hunan Bureau Statistic. Accessed December, 2022 http://222240193190/2021tjnj/indexchhtm.

Hodas, N., Loh, M., Shin, H.M., Li, D., Bennett, D., Mckone, T.E., Jolliet, O., Weschler, C.J., Jantunen, M., Lioy, P., Fantke, P., 2016. Indoor inhalation intake fractions of fine particulate matter: review of influencing factors. Indoor Air 26 (6), 836–856.

Hoffmann, B., Luttmann-Gibson, H., Cohen, A., Zanobetti, A., De Souza, C., Foley, C., Suh, H.H., Coull, B.A., Schwartz, J., Mittleman, M., Stone, P., Horton, E., Gold, D.R., 2012. Opposing effects of particle pollution, ozone, and ambient temperature on arterial blood pressure. Environ. Health Perspect. 120, 241–246.

Hu, J.L., Li, W.S., Gao, Y., Zhao, G., Jiang, Y.X., Wang, W.D., Cao, M.Y., Zhu, Y.X., Niu, Y., Ge, J.B., Chen, R.J., 2022. Fine particulate matter air pollution and subclinical cardiovascular outcomes: a longitudinal study in 15 Chinese cities. Environ. Int. 163.

Hu, L.W., Qian, Z.M., Bloom, M.S., Nelson, E.J., Liu, E., Han, B., Zhang, N., Liu, Y.M., Ma, H.M., Chen, D.H., Yang, B.Y., Zeng, X.W., Chen, W., Komppula, M., Leskinen, A., Hirvonen, M.R., Roponen, M., Jalava, P., Bai, Z.P., Dong, G.H., 2018. A panel study of airborne particulate matter concentration and impaired cardiopulmonary function in young adults by two different exposure measurement. Atmos. Environ. 180, 103–109.

Huang, Y., Du, W., Chen, Y.C., Shen, G.F., Su, S., Lin, N., Shen, H.Z., Zhu, D., Yuan, C.Y., Duan, Y.H., Liu, J.F., Li, B.G., Tao, S., 2017. Household air pollution and personal inhalation exposure to particles (TSP/PM2.5/PM1.0/PM0.25) in rural Shanxi, North China. Environ Pollut 231, 635–643.

Huang, Y., Wang, J.Z., Chen, Y., Chen, L., Chen, Y.C., Du, W., Liu, M., 2022. Household PM2.5 pollution in rural chinese homes: levels, dynamic characteristics and seasonal variations. Sci. Total Environ. 817.

Lewington, S., Li, L.M., Sherliker, P., Guo, Y., Millwood, I., Bian, Z., Whitlock, G., Yang, L., Collins, R., Chen, J.S., Wu, X.P., Wang, S.J., Hu, Y.H., Jiang, L., Yang, L.Q., Lacey, B., Peto, R., Chen, Z.M., 2012. Seasonal variation in blood pressure and its relationship with outdoor temperature in 10 diverse regions of China: the China kadoorie biobank. J. Hypertens. 30, 1383–1391.

Li, H.Y., Wu, S.W., Pan, L., Xu, J.H., Shan, J., Yang, X., Dong, W., Deng, F.R., Chen, Y.H., Shima, M., Guo, X.B., 2018. Short-term effects of various ozone metrics on cardiopulmonary function in chronic obstructive pulmonary disease patients: results from a panel study in Beijing, China. Environ. Pollut. 232, 358–366.

Liang, R.J., Zhang, B., Zhao, X.Y., Ruan, Y.P., Lian, H., Fan, Z.J., 2014. Effect of exposure to PM2.5 on blood pressure: a systematic review and meta-analysis. J. Hypertens. 32 (11), 2130–2141.

Lin, Z.J., Niu, Y., Chen, R.J., Xu, W.X., Li, H.C., Liu, C., Cai, J., Zhao, Z.H., Kan, H.D., Qiao, L.P., 2017. Fine particulate matter constituents and blood pressure in patients with chronic obstructive pulmonary disease: a panel study in Shanghai, China. Environ. Res. 159, 291–296.

Li, Z.Y., Liu, Y.S., Lu, T.J., Peng, S.X., Liu, F.F., Sun, J.H., Xiang, H., 2021. Acute effect of fine particulate matter on blood pressure, heart rate and related inflammation biomarkers: a panel study in healthy adults. Ecotoxicol. Environ. Saf. 228.

Linares, C., Diaz, J., 2008. Impact of high temperatures on hospital admissions: comparative analysis with previous studies about mortality (Madrid). Eur. J. Pub. Health 18, 317–322.

Liu, C., Chen, R.J., Zhao, Y.H., Ma, Z.W., Bi, J., Liu, Y., Meng, X., Wang, Y.F., Chen, X.X., Li, W.H., Kan, H.D., 2017. Associations between ambient fine particulate air pollution and hypertension: a nationwide cross-sectional study in China. Sci. Total Environ. 584, 869–874.

Madsen, C., Nafstad, P., 2006. Associations between environmental exposure and blood pressure among participants in the Oslo health study (HUBRO). Eur. J. Epidemiol. 21 (7), 485–491.

Mccracken, J.P., Smith, K.R., Diaz, A., Mittleman, M.A., Schwartz, J., 2007. Chimney stove intervention to reduce long-term wood smoke exposure lowers blood pressure among guatemalan women. Environ. Health Perspect. 115, 996–1001.

Meier, R., Cascio, W.E., Ghio, A.J., Wild, P., Danuser, B., Riediker, M., 2014. Associations of short-term particle and noise exposures with markers of cardiovascular and respiratory health among highway maintenance workers. Environ. Health Perspect. 122 (7), 726–732.

Miersch, A., Vogel, M., Gausche, R., Siekmeyer, W., Pfaffle, R., Dittrich, K., Kiess, W., 2013. Influence of seasonal variation on blood pressure measurements in children, adolescents and young adults. Pediatr. Nephrol. 28, 2343–2349.

Modesti, P.A., Bamoshmoosh, M., Rapi, S., Massetti, L., Al-Hidabi, D., Al Goshae, H., 2013. Epidemiology of hypertension in Yemen: effects of urbanization and geographical area. Hypertens. Res. 36, 711–717.

Oh, E., Choi, K.H., Kim, S.R., Kwon, H.J., Bae, S., 2022. Association of indoor and outdoor short-term PM2.5 exposure with blood pressure among school children. Indoor Air 32 (3).

Pangaribuan, M., Chuang, K.J., Chuang, H.C., 2019. Association between exposures to air pollution and biomarkers of cardiovascular disease in northern Taiwan. Atmos. Pollut. Res. 10, 1250–1259.

Pitchika, A., Hampel, R., Wolf, K., Kraus, U., Cyrys, J., Babisch, W., Peters, A., Schneider, A., 2017. Long-term associations of modeled and self-reported measures of exposure to air pollution and noise at residence on prevalent hypertension and blood pressure. Sci. Total Environ. 593, 337–346.

Ren, M., Zhang, H.H., Benmarhnia, T., Jalaludin, B., Dong, H.T., Wu, K.P., Wang, Q., Huang, C.R., 2019. Short-term effects of real-time personal PM2.5 exposure on ambulatory blood pressure: a panel study in young adults. Sci. Total Environ. 697.

Rosenthal, T., 2004. Seasonal variations in blood pressure. Am. J. Geriatr. Cardiol. 13, 267–272.

Shan, M., Yang, X.D., Ezzati, M., Chaturvedi, N., Coady, E., Hughes, A., Shi, Y.H., Yang, M., Zhang, Y.X., Baumgartner, J., 2014. A feasibility study of the association of exposure to biomass smoke with vascular function, inflammation, and cellular aging. Environ. Res. 135, 165–172.

Sinaga, D., Setyawati, W., Cheng, F.Y., Lung, S.C.C., 2020. Investigation on daily exposure to PM(2.5)in Bandung city, Indonesia using low-cost sensor. J. Expo. Sci. Environ. Epidemiol. 30, 1001–1012.

Smargiassi, A., Goldberg, M.S., Wheeler, A.J., Plante, C., Valois, M.F., Mallach, G., Kauri, L.M., Shutt, R., Bartlett, S., Raphoz, M., Liu, L., 2014. Associations between personal exposure to air pollutants and lung function tests and cardiovascular indices among children with asthma living near an industrial complex and petroleum refineries. Environ. Res. 132, 38–45.

Song, J.L., Gao, Y., Hu, S., Medda, E., Tang, G.G., Zhang, D., Zhang, W.B., Li, X., Li, J., Renzi, M., Stazi, M.A., Zheng, X., 2021. Association of long-term exposure to PM2.5 with hypertension prevalence and blood pressure in China: a cross-sectional study. BMJ Open 11 (12).

Sun, J., Niu, X.Y., Zhang, B., Zhang, L.M., Yu, J.J., He, K., Zhang, T., Wang, Q.Y., Xu, H.M., Cao, J.J., Shen, Z.X., 2022. Clarifying winter clean heating importance: insight chemical compositions and cytotoxicity exposure to primary and aged pollution emissions in China rural areas. J. Environ. Manag. 320.

Sun, J., Shen, Z.X., Zhang, L.M., Zhang, Y., Zhang, T., Lei, Y.L., Niu, X.Y., Zhang, Q., Dang, W., Han, W.P., Cao, J.J., Xu, H.M., Liu, P.P., Li, X.X., 2019. Volatile organic compounds emissions from traditional and clean domestic heating appliances in Guanzhong Plain, China: Emission factors, source profiles, and effects on regional air quality. Environ Int 133.

Tao, S., Ru, M.Y., Du, W., Zhu, X., Zhong, Q.R., Li, B.G., Shen, G.F., Pan, X.L., Meng, W.J., Chen, Y.L., Shen, H.Z., Lin, N., Su, S., Zhuo, S.J., Huang, T.B., Xu, Y., Yun, X., Liu, J.F., Wang, X.L., Liu, W.X., Cheng, H.F., Zhu, D.Q., 2018. Quantifying the rural residential energy transition in China from 1992 to 2012 through a representative national survey. Nat. Energy 3, 567–573.

Van Nunen, E., Hoek, G., Tsai, M.Y., Probst-Hensch, N., Imboden, M., Jeong, A., Naccarati, A., Tarallo, S., Raffaele, D., Nieuwenhuijsen, M., Vlaanderen, J., Gulliver, J., Amaral, A.F.S., Vineis, P., Vermeulen, R., 2021. Short-term personal and outdoor exposure to ultrafine and fine particulate air pollution in association with blood pressure and lung function in healthy adults. Environ. Res. 194.

Wang, X.J., Zou, Z.Y., Dong, B., Dong, Y.H., Ma, Y.H., Gao, D., Yang, Z.G., Wu, S.W., Ma, J., 2019. Association of School Residential PM2.5 with childhood high blood pressure: results from an observational study in 6 cities in China. Int. J. Environ. Res. Public Health 16 (14).

Warren, H.R., Evangelou, E., Cabrera, C.P., Gao, H., Ren, M.X., Mifsud, B., Ntalla, I., Surendran, P., Liu, C.Y., Cook, J.P., Kraja, A.T., Drenos, F., Loh, M., Verweij, N., Marten, J., Karaman, I., MPS, Lepe, O'reilly, P.F., Knight, J., Snieder, H., Kato, N., He, J., Tai, E.S., Said, M.A., Porteous, D., Alver, M., Poulter, N., Farrall, M., Gansevoort, R.T., Padmanabhan, S., Magi, R., Stanton, A., Connell, J., SJL, Bakker, Metspalu, A., Shields, D.C., Thom, S., Brown, M., Sever, P., Esko, T., Hayward, C., Van Der Harst, P., Saleheen, D., Chowdhury, R., Chambers, J.C., Chasman, D.I., Chakravarti, A., Newton-Cheh, C., Lindgren, C.M., Levy, D., Kooner, J.S., Keavney, B., Tomaszewski, M., Samani, N.J., JMM, Howson, Tobin, M.D., Munroe, P.B., Ehret, G.B., Wain, L.V., Barnes, M.R., Tzoulaki, J., Caulfield, M.J., Elliott, P., ICBP, I.C.B.P., Consortium, C.E., Consortium, E., Consortium, T.D.-G., Consortium, G.D., CHAR, Genome, IGB, Pressure, UBC, Consortium, 2017. Genome-wide association analysis identifies novel blood pressure loci and offers biological insights into cardiovascular risk. Nat Genet 49, 403–415.

Wen, H.X., Nie, P.Y., Liu, M., Peng, R., Guo, T., Wang, C., Xie, X.B., 2023. Multi-health effects of clean residential heating: evidences from rural China's coal-to-gas/electricity project. Energy Sustain. Dev. 73, 66–75.

World Health Organization (WHO), 2021. WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. . https://apps.who.int/iris/handle/10665/345329.

Wu, H., Zhang, Y.X., Zhao, M., Liu, W.H., Magnussen, C.G., Wei, J., Xi, B., 2022b. Short-term effects of exposure to ambient PM1 on blood pressure in children and adolescents aged 9 to 18 years in Shandong Province, China. Atmos Environ 283.

Wu, D., Zheng, H.T., Li, Q., Jin, L., Lyu, R., Ding, X., Huo, Y.Q., Zhao, B., Jiang, J.K., Chen, J.M., Li, X.D., Wang, S.X., 2022a. Toxic potency-adjusted control of air pollution for solid fuel combustion. Nat. Energy 7, 194–202.

Xu, N., Lv, X.F., Yu, C.C., Guo, Y.F., Zhang, K.X., Wang, Q., 2020. The association between short-term exposure to extremely high level of ambient fine particulate matter and blood pressure: a panel study in Beijing, China. Environ Sci Pollut R 27 (22), 28113–28122.

Ye, H.Z., Tang, J., Luo, L.Q., Yang, T.J., Fan, K.D., Xu, L., 2022. High-normal blood pressure (prehypertension) is associated with PM2.5 exposure in young adults. Environ. Sci. Pollut. Res. 29, 40701–40710.

Yin, W.J., Hou, J., Xu, T., Cheng, J., Wang, X.Y., Jiao, S.L., Wang, L., Huang, C., Zhang, Y.J., Yuan, J., 2017. Association of individual-level concentrations and human respiratory tract deposited doses of fine particulate matter with alternation in blood pressure. Environ. Pollut. 230, 621–631.

Yun, X., Shen, G.F., Shen, H.Z., Meng, W.J., Chen, Y.L., Xu, H.R., Ren, Y., Zhong, Q.R., Du, W., Ma, J.M., Cheng, H.F., Wang, X.L., Liu, J.F., Wang, X.J., Li, B.G., Hu, J.Y., Wan, Y., Tao, S., 2020. Residential solid fuel emissions contribute significantly to air pollution and associated health impacts in China. Sci. Adv. 6.

Zhang, J.X., Zhou, Q.F., Su, R.J., Sun, Z.D., Zhang, W.F., Jin, X.T., Zheng, Y.X., 2020. Cardiac dysfunction and metabolic remodeling due to seasonally ambient fine particles exposure. Sci. Total Environ. 721.

Zhao, A., Chen, R.J., Wang, C.C., Zhao, Z.H., Yang, C.Y., Lu, J.X., Chen, X., Kan, H.D., 2015. Associations between size-fractionated particulate air pollution and blood pressure in a panel of type II diabetes mellitus patients. Environ. Int. 80, 19–25.

Zhou, B.F., 2002. Predictive values of body mass index and waist circumference for risk factors of certain related diseases in Chinese adults - study on optimal cut-off points of body mass index and waist circumference in Chinese adults. Biomed. Environ. Sci. 15, 83–96.