

## Independent and combined associations of solid-fuel use and smoking with obesity among rural Chinese adults

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## **Independent and combined associations of solid fuel use and smoking with obesity among rural Chinese adults**

### **Running title**

solid fuel use, smoking and obesity indices

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### **Abbreviation:**

BFP, body fat percentage; BMI, body mass index; CI: confidence interval; HAP, household air pollution; SD, standard deviation. VFI, visceral fat index; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio;

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**Abstract**

Although solid fuel use or smoking is associated with obesity measured by body mass index (BMI), research on their interactive effects on general and central obesity is limited. Data of 20,140 individuals in the Henan Rural Cohort Study was examined the independent and combined associations of solid fuel use and smoking with prevalent obesity, which was measured by BMI, waist circumference (WC), waist-to-hip ratio (WHR), waist-to-height ratio (WHtR), body fat percentage (BFP) and visceral fat index (VFI). Multiple adjusted logistic regression models showed that the OR (95%CI) of prevalent obesity measured by BMI associated with exposure to solid fuels alone or with smoking was 0.78 (0.70,0.86) or 0.46 (0.32,0.66), compared to neither smoking nor solid fuel exposure. Similar results had been found in other obese anthropometric indices and in the results of linear regression analysis. The results indicated that solid fuel use and smoking have a synergistic effect on reduction in obesity indices. The effects of household air pollution from solid fuel use and smoking on obesity should be considered when exploring the influencing factors of obesity.

**Keywords:** household air pollution, solid fuel use, smoking, obesity indices, adults, rural population.

## **Introduction**

Household air pollution (HAP) poses a great health public concern globally. It is well known that tobacco smoking and solid fuel-related smoke are two major sources of HAP (Landrigan PJ, Miri et al. 2019). Although many efforts have been taken to promote the use of clean fuels, particularly in developing countries, including China, nearly 2.7 billion people still rely on solid fuels heavily (Calcinotto et al. 2019). HAP, sourced from solid fuel uncompleted combustion, has been reported to increase adverse health effects, such as cardiovascular and respiratory diseases (Ezzati & Kammen 2001, McCracken et al. 2012, Noubiap et al. 2015, Smith & Mehta 2003). Results from the Global Burden of Disease Study 2015 demonstrated that solid fuel-related HAP is the second environmental risk factor and contributes to 2.9 million premature deaths and 85.6 million disability adjusted life years in 2015 (Forouzanfar et al. 2016). Smoking causes about 6 million preventable deaths worldwide each year (Fernandes et al. 2018).

Obesity is a multifactorial disease that represents a growing threat to public health worldwide (Collaborators et al. 2017). The prevalence of obesity and overweight in rural China was 16.0% and 34.1 % in 2018, respectively (Liu et al. 2018a). It is important to investigate factors influencing obesity. Although body mass index (BMI) has been widely used to evaluate general obesity, it is not able to distinguish between lean and fat mass and does not reflect body fat distribution. Body fat percentage (BFP), as an indicator of increased body fat, is associated with a prominent effect on cardio-metabolic changes (Joseph et al. 2011). Visceral fat index (VFI) is accepted to assess visceral fat which is highly active considering the metabolic aspect (Kim et al. 2011). Abdominal obesity is usually expressed by waist circumference (WC), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR). Several studies have implicated abdominal obesity as a stronger predictor than overall obesity of insulin resistance and dyslipidemia in the general population (Concepcion et al. 2001, Despres 2001). Thus, these measurements of anthropometric indices (BMI, WC, WHR, WHtR, BFP, VFI) were used to more accurately predict obesity.

Both solid fuel and smoking-related HAP are avoidable risk factors that may have a combined association with adverse health effects (Firdaus & Ahmad 2011, Viegli et al. 2004). Individuals can be simultaneously exposed to them in their daily lives (Gordon et al. 2014). Several studies have shown that using solid fuel for cooking and smoking were independently associated with a lower risk of obesity (Amegah et al. 2020, Cheng et al. 2015, Chiolero et al. 2008, Wang 2015). One study conducted in Ghana indicated that solid fuel users were at a higher risk for weight loss, compared to

clean fuels users (Amegah et al. 2020). Another study conducted in Guangzhou, China showed that solid fuel smoke exposure was associated with reduction in BMI in women with chronic obstructive pulmonary disease (COPD) (Cheng et al. 2015). There is a variety of evidence that smoking is associated with bodyweight decline among adults (Chiolero et al. 2008, Wang 2015). However, in recent years, there was some research suggesting the associations of secondhand smoke and ambient air pollution exposure with increased BMI among children and adults (Eze et al. 2015, Jerrett et al. 2014, Liu et al. 2020, McConnell et al. 2015).

Available evidence showed that both solid fuel- and smoking-related smoke can cause dysfunction of energy metabolism by inducing oxidative stress and inflammatory response and ultimately contribute to reduce body weight (Irie et al. 2005, Mizoue et al. 2007). However, there is still a lack of population-based study to investigate the potential joint association of solid fuel- and smoking-related HAP on obesity. Therefore, we aimed to assess the independent and joint associations of HAP sourced from smoking and solid fuel use with obesity by analyzing the data from the Henan Rural Cohort Study.

## **Material and Methods**

### **Study Population**

During 2015-2017, the Henan Rural Cohort study was conducted across five counties (Suiping, Yuzhou, Xinxiang, Tongxu, and Yima) in Henan province, China. The methods of baseline health survey have been fully described before (Liu et al. 2019, Liu et al. 2018b). Briefly, we recruited randomly 39,259 participants aged 18-79 years living in the rural areas of five counties by using a multistage stratified cluster sampling method. After excluding individuals without self-cooking meals (n=17,694), individuals with missing data on fuel type (n=308) and anthropometric measures (including BMI, WC, WHR, WHtR, BFP, and VFI) (n=134), the data of 21,040 participants were left for analysis. This study had complied to the principles outlined in the Declaration of Helsinki. Zhengzhou University Life Science Ethics Committee approved the study, and all participants provided written informed consent.

### **Ascertainment of obesity**

Obesity anthropometric measurements including height, weight, hip circumference, WC, BFP, and VFI were collected by trained staffs using standard tools. Height was measured to the nearest 0.1 cm using a standard right-angle device and a fixed measurement tape with shoes off. Weight was measured

to the nearest 0.1 kg using a weight measurement device (V. BODY HBF-371, OMRON, Japan) with light clothing. WC and hip circumference were measured to the nearest 0.1cm using a non-elastic tape with light clothing at the level of 1.0cm above the navel and the maximal level of the hip, respectively. For each participant, BFP and VFI were measured with light clothing and shoes off using a bioelectrical impedance analysis device (OMRON V. BODY HBF-371) in accordance with the operating instructions. BMI was calculated by dividing weight (kg) by height (m) squared and WHR or WHtR was assessed by dividing WC (cm) or hip circumference (cm) by height (cm). The cut-off values for different obesity indices were as follows: each participant with a BMI  $\geq 28$  kg/m<sup>2</sup> (Zhou & Cooperative Meta-Analysis Group of the Working Group on Obesity in 2002), WC  $\geq 90$  or 80cm for men or women (Abbasi et al. 2016), WHR  $\geq 0.90$  or 0.85 for men or women (Rezaei et al. 2017), WHtR  $\geq 0.5$  (Srinivasan et al. 2009), BFP  $\geq 25\%$  or 30% for men or women (Minematsu et al. 2011) or a VFI  $\geq 10$  (Liu et al. 2020) was defined as obesity.

### **Assessment of exposure**

Information on participants' smoking status and cooking fuel choices was collected by using a standardized questionnaire. First, smoking status was categorized as smoking or non-smoking. This variable was derived from the response to the questions in the questionnaire: "Do you currently smoke?". Participants who smoked more than one cigarette per day in the past six months were classified as smoking (Li et al. 2020). Afterwards, participants were asked if they cooked at home, and those who reported regular cooking (weekly or more frequently) were asked additional questions, including the primary fuel type used and kitchen ventilation. Fuel types included coal gas, natural gas, electricity, coal, and firewood. Individuals living in households using electricity, coal gas, and natural gas were considered as the relative clean fuel use group, while those residing in households using coal and firewood were taken as solid fuel users (Yu et al. 2020, Yu et al. 2018). According to the two major sources of HAP, we divided participants into groups of the following four exposure types: (1) clean fuel use and non-smoking, (2) clean fuel use and smoking, (3) solid fuel use and non-smoking, (4) solid fuel use and smoking.

### **Covariates**

Information was collected on covariates, such as the participant's socio-demography, education level (elementary school or below, junior high school, high school or above), personal monthly income

(<500RMB, 500-999RMB, ≥1000 RMB), marital status (married/cohabiting, widowed/single/divorced/separation), drinking (no, yes), physical activity (low, moderate, high) (Clark et al. 2013) and dietary habits (adequate fruit and vegetable intake (≥ 500g/day) (no, yes), high fat diet (≥ 75g/day) (no, yes)) (Shen et al. 2013) using a standardized questionnaire. Dietary data was collected by using a food frequency questionnaire (FFQ), which is suited to assess the dietary of rural residents with a accepted reproducibility and validity (Xue et al. 2020). In a brief, based on five consumption frequencies (never, daily, weekly, monthly and yearly), participants were asked about their quantity (grams) and frequency (never, day, week, month and year) in the past 12 months. The information of kitchen ventilation was derived from the question in questionnaire: "What is the main approach of ventilation in your kitchen when you cook at home?", which is a single choice question with options including exhaust hood, exhaust fan, and open-window.

### **Statistical analysis**

The continuous and categorical variables were expressed as the mean (standard deviation (SD)) and number (percent). The differences in continuous and categorical variables between different exposure types were examined by using the Student's t-test and Chi-square test, respectively. Linear regression and logistic regression analysis were applied to assess the independent and combined associations of solid fuel use and smoking on continuous obesity indices and prevalent obesity. A fully adjusted model was constructed, which was adjusted for age, gender, marital status, education level, monthly income, drinking status, physical activity, fruit and vegetable intake, high fat diet, and kitchen ventilation. To test the robustness of the results, we performed the following sensitivity analyses: (1) different BMI cut-off values (28kg/m<sup>2</sup> vs. 30 kg/m<sup>2</sup>) were used, and (2) participants with a history of hypertension, type 2 diabetes mellitus or dyslipidemia were excluded. All data analysis was conducted in R version 3.5.1 and all statistical significances were set a *P-value* < 0.05 at two-tail.

## **Results**

### **Characteristics of the population**

Table 1 exhibited distributions of demographic characteristics between the solid fuel use and clean fuel use groups. The mean (SD) age was 55.3 (11.9) years among all participants. There were significant differences in age, gender, education level, personal monthly income, marital status, smoking status, drinking status, high fat intake, vegetable and fruit intake, physical activity, and kitchen

ventilation between the solid fuel use and clean fuel use groups. Compared to the clean fuel users, solid fuel users were more likely to be older, female gender, have lower socioeconomic status (lower education and lower income), poorer dietary nutrition and higher physical activity level. They were less likely to have a diet in high fat (9.7% vs. 18.0%) and adequate fruit and vegetable intake (46.0% vs. 48.7%) (all  $P < 0.05$ ). 31.9% of solid fuel users and 29.6% of clean fuel users were categorized as high physical activity group.

### **Analyzing independent association of solid fuel use and smoking on obesity**

**Table 2** showed that in the fully-adjusted models, individuals using solid fuels in cooking had a lower BMI ( $\beta$ : -0.58, 95%CI: -0.71, -0.46), WC ( $\beta$ : -1.56, 95%CI: -1.92, -1.20), WHR (%) ( $\beta$ : -1.01, 95%CI: -1.27, -0.75), WHtR (%) ( $\beta$ : -0.82, 95%CI: -1.04, -0.59), BFP ( $\beta$ : -0.80, 95%CI: -0.96, -0.65), and VFI ( $\beta$ : -0.65, 95%CI: -0.79, -0.50), compared to those using clean fuels. Smokers had a lower BMI ( $\beta$ : -0.68, 95%CI: -0.88, -0.48), WC ( $\beta$ : -1.40, 95%CI: -1.97, -0.83), WHR ( $\beta$ : -0.29, 95%CI: -0.70, 0.12), WHtR ( $\beta$ : -0.84, 95%CI: -1.20, -0.48), BFP ( $\beta$ : -1.04, 95%CI: -1.29, -0.80), and VFI ( $\beta$ : -0.96, 95%CI: -1.19, -0.74), compared to non-smoker. Similar results from logistic regression analysis were observed in **Table 3**.

### **Analyzing combined association of solid fuel use and smoking on obesity**

**Figure 1** and **Tables S1** showed that compared to those non-smoking and clean-fuel cooking, the ORs of these with smoking and clean-fuels cooking, with non-smoking and solid-fuel cooking, and with smoking and solid-fuel cooking were 0.72, 0.78, and 0.46, respectively, of the prevalent obesity defined by BMI. The matched figures of the estimated ORs in the prevalent obesity measured by WC were 0.85, 0.83, and 0.50, respectively; in the prevalent obesity defined by WHR were 0.93, 0.86 and 0.46, by WHtR were 0.83, 0.83 and 0.45, by BFP were 0.75, 0.76 and 0.38, and by VFI were 0.74, 0.79 and 0.44, respectively. The similar results were observed from linear regression analysis. Sensitivity analysis suggested no significant change in the results after excluding participants with a history of hypertension, dyslipidemia or type 2 diabetes mellitus (**Table S2-S4**), and the robust results remained to the use of different BMI cut-off values (**Table S5**).

### **Discussion**

To our knowledge, this is the first study to examine the independent and combined associations of solid fuel use and smoking on different objectively measured indices of obesity in a large rural

population in China. The study showed that smoking and solid fuel using were associated with lower prevalent obesity, regardless of the choice of obesity indices, and that the combined association of them was more pronounced on obesity related traits.

In the limited studies examining the association between HAP sourced from solid fuel combustion and changes in body weight, the relationship between weight loss and solid fuel use was observed. The findings from the Ghana Demographic and Health Survey (GDHS), including 4751 adult Ghanaian women, indicated that charcoal users had reduced 3.08 kg (95% CI: 2.04, 4.12) in body weight and 0.81 kg/m<sup>2</sup> (95%CI: 0.29, 1.33) BMI, compared to clean fuel users (Amegah et al. 2020). One study suggested that women with chronic obstructive pulmonary disease (COPD) had a lower BMI which may be attributable to exposure to solid fuels-related HAP in Guangzhou, China (Cheng et al. 2015). Another study conducted in Guangdong, China, including 1986 residents aged 40-93 years also found that participants with exposure to solid fuel alone tended to be underweight (Zheng et al. 2020). Whilst, accumulated evidence suggested that smoking is associated with weight loss (Chiolero et al. 2008, Molarius et al. 1997, Stavropoulos-Kalinoglou et al. 2008, Wang 2015). Examining the history of different smoking habits and weight changes in 42 populations to observe the relationship between smoking and relative weight, the World Health Organization Monitoring Cardiac Disease (WHO MONICA) survey found that regular cigarette smoking men and women were on average 1.1 kg/m<sup>2</sup> and 0.9 kg/m<sup>2</sup> leaner than their never-smoking counterparts (Molarius et al. 1997). A study examining the potential association between smoking and weight in Rheumatoid arthritis patients found that both male and female smokers tended to have decreased BMI compared with their non-smoking counterparts (Stavropoulos-Kalinoglou et al. 2008).

We found that the combined exposure to solid fuel and smoking usually tended to yield higher ORs in health outcomes according to previous studies (Fernandes et al. 2018, Lin et al. 2008, Suryadhi et al. 2019). One study indicated that the ORs for acute lower respiratory infection was 1.21 (95% CI, 0.98 to 1.50) in HAP from solid fuel use and 1.12 (95% CI, 0.97 to 1.29) in exposure to environmental tobacco smoke, but 1.36 (95% CI, 1.16 to 1.61) in exposure to both (Suryadhi et al. 2019). Fernandes et al. reported that doubly exposed (simultaneous exposure to the smoke of tobacco and solid fuel) participants had a higher frequency of uncontrolled asthma and severe asthma (Fernandes et al. 2018). Lin et al. had calculated the annual number of lung cancer and COPD deaths avoidable by reducing exposure to smoking and solid fuels and concluded that if smoking and solid fuel use remain at current

levels between 2003 and 2033, 82% of COPD deaths and 75% of lung cancer deaths would be attributable to the combined association of smoking and solid fuel use (Lin et al. 2008).

The possible biological mechanisms underlying the association between exposure to HAP sourced from solid fuel use or smoking and decreased obesity indices still deserved exploration. The potential explanations may be as follows. For solid fuel use, the possible reasons for causing weight loss may due to the air pollutants released during combustion, which includes carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs), etc (Jetter et al. 2012, Shen et al. 2013, Weinstein et al. 2017). CO poisoning can affect energy metabolism by increasing mitochondrial production and mitochondrial decoupling, as well as white adipose tissue remodeling, leading to the reduction in adipocyte size and weight loss in obese mice (Hosick et al. 2014). PAHs and VOCs metabolites have been shown to cause oxidative DNA damage (Li et al. 2015, Wang et al. 2015), and generate excessive reactive oxygen species by increasing energy consumption or metabolic rate, and both were negatively associated with BMI (Irie et al. 2005, Loft & Poulsen 1996, Mizoue et al. 2007). Additionally, individuals using solid fuels may have a higher chance for poor nutrition and high-intensive physical activity which were related to weight loss, because solid fuels are mainly used in low-income households (Amegah & Jaakkola 2016, Tu et al. 2019, Zulu & Richardson 2013), especially in rural regions. Smoking may lead to weight loss by increasing metabolic rate, reducing metabolic efficiency, or appetite. The metabolic effect of smoking can explain the lighter weight of smokers. For example, smoking four cigarettes that contain 0.8mg of nicotine can increase resting energy expenditure by 3.3% for 3 hours (Collins et al. 1994). Besides, nicotine may induce the effect of acute anorexia: in 2 hours, hunger and food consumption were negatively correlated, and satiety was positively correlated with increased doses of nicotine (Jessen et al. 2005). HAP from solid fuel and smoking has certain same constituents (Bruce et al. 2000) and similarity in particles size (Bernstein 2004, Naeher et al. 2007), and the impairments associated with solid fuel use is analogous to those related to smoking (Gordon et al. 2014, Newby et al. 2015), which may explain the observation that exposure to solid fuel and smoking has a significantly higher association with the reduction of obesity indices. The underlining mechanism is warranted to reveal by other studies.

Several limitations were found in our study that should be considered. Firstly, owing to using baseline cross-sectional data from the Henan Rural Cohort Study for analysis in this paper, the causal associations between solid fuel use and smoking on obesity cannot be estimated. Thus, prospective

studies are needed to confirm the results of this study. Secondly, the data on the years of using solid fuels and exchanging into clean fuels for cooking were not collected, which may be under- or over-estimate the effect of solid cooking fuel and smoking on obesity. Thirdly, the solid fuel-related HAP was estimated by self-reported data, which may lead to exposure misclassification. Finally, data on the level of HAP exposure such as PM<sub>2.5</sub>, mosquito coils, pesticides and volatile organic compounds were not collected at baseline in this study. They need to be measured in future study to assess HAP and other air pollutants accurately.

### **Conclusions**

We found HAP exposure from solid fuel use and smoking to be associated with reduced prevalent obesity indices in the Chinese rural population. Our study should be an important contribution added in the literature on the environmental determinants of obesity and the potential health harms of solid fuels. The findings of the study would inform intervention policies to combat the metabolic effects of HAP from solid fuel use or smoking. It is imperative to validate our findings and elucidate biological mechanisms through robust study designs in different geographical areas.

### **Ethics approval and consent to participate**

This study was approved by the Zhengzhou University Life Science Ethics Committee (Code: [2015] MEC (S128)) and informed consent was acquired from each participant before this survey.

### **Consent for publication**

Not applicable

### **Availability of data and materials**

The datasets generated and analyzed during the current study, as well as the R code for reproducing the results, are available upon request to the corresponding author.

### **Competing Interests**

All authors had declared no conflict of interest.

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#### **Author contributions**

CW, JH and MP suggested and conceptualized the study. All authors designed the study and developed the study protocol. MP and JG analyzed the data and drafted the manuscript. JH, MP, RL, RT, RC and HC interpreted the results and contributed to the critical revision of the manuscript. All authors have read and approved the final manuscript.

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**Figure legends**

**Figure 1** Combined association of solid fuel use and smoking with obesity indices (continuous) and prevalent obesity (dichotomous) were analyzed by linear regression and logistic regression models, respectively. All models adjusted for age, gender, marital status, education level, personal monthly income, drinking status, high fat diet, adequate vegetable and fruit intake, physical activity, and kitchen ventilation. The estimated combined association and their corresponding 95% confidence interval (95%CI) were represented by dots and lines, respectively. The estimated values and their corresponding 95% CI were presented in **Table S1**.

**Table 1 Characteristics of the study population**

<b>Characteristics</b>	<b>Total n= (21040)</b>	<b>Clean fuel use n= (16911)</b>	<b>Solid fuel use n= (4129)</b>	<b>P</b>
Age (years, mean ± SD)	55.3±11.9	54.0±11.8	60.7±10.5	<0.001 <sup>a</sup>
Gender (n, %)				0.001 <sup>b</sup>
Men	4784(22.7)	3924(23.2)	860(20.8)	
Women	16256(77.3)	12987(76.8)	3269(79.2)	
Marital status (n, %)				<0.001 <sup>b</sup>
Married/cohabitation	18787(88.9)	15226(89.7)	3561(85.9)	
Unmarried/divorced/widowed	2342(11.1)	1756(10.3)	586(14.1)	
Education level (n, %)				<0.001 <sup>b</sup>
Elementary school or below	10184(48.2)	7426(43.7)	2758(66.5)	
Junior high school	7784(36.8)	6682(39.3)	1102(26.6)	
High school or above	3161(15.0)	2874(16.9)	287(6.9)	
Personal monthly income (n, %)				<0.001 <sup>b</sup>
<500RMB	7548(35.7)	5508(32.4)	2040(49.2)	
500–999 RMB	6699(31.7)	5536(32.6)	1163(28.0)	
≥1000RMB	6882(32.6)	5938(35.0)	944(22.8)	
Smoking status (n, %)				<0.001 <sup>b</sup>
No	18715(88.9)	14966(88.5)	3749(90.8)	
Yes	2325(11.1)	1945(11.5)	380(9.2)	
Drinking status (n, %)				<0.001 <sup>b</sup>
No	18773(89.2)	14944(88.4)	3829(92.7)	
Yes	2267(10.8)	1967(11.6)	300(7.3)	
High fat diet (yes, n, %)	3458(16.4)	3054(18)	404(9.7)	<0.001 <sup>b</sup>
Adequate vegetable and fruit intake (yes, n, %)	10169(48.1)	8263(48.7)	1906(46.0)	0.002 <sup>b</sup>
Physical activity (n, %)				<0.001 <sup>b</sup>
Low	6209(29.4)	5149(30.3)	1060(25.6)	
Moderate	8575(40.6)	6812(40.1)	1763(42.5)	
High	6345(30.0)	5021(29.6)	1324(31.9)	
Obesity (mean ± SD)				
BMI	24.9±3.6	25.0±3.6	24.3±3.6	0.174 <sup>a</sup>
WC	83.3±10.3	83.6±10.3	82.0±10.4	0.41 <sup>a</sup>
WHR (%)	88.3±7.6	88.3±7.7	88.1±7.3	0.057 <sup>a</sup>
WHtR (%)	52.8±6.5	52.8±6.5	52.6±6.7	0.001 <sup>a</sup>
BFP	31.6±6.2	31.5±6.2	31.8±6.3	0.215 <sup>a</sup>
VFI	8.8±4.4	8.9±4.4	8.6±4.3	0.023 <sup>a</sup>
Hypertension (yes, n, %) *	6831(32.5)	5358(31.7)	1473(35.7)	<0.001 <sup>b</sup>
Dyslipidemia (yes, n, %) *	8069(38.4)	6546(38.8)	1523(36.9)	0.029 <sup>b</sup>
Type 2 diabetes mellitus (yes, n, %)	1860(8.8)	1472(8.7)	388(9.4)	0.160 <sup>b</sup>
Ventilation condition (n, %) *				<0.001 <sup>b</sup>
Exhaust hood	5527(26.4)	5269(31.2)	258(6.3)	
Exhaust fan	4692(22.4)	3907(23.1)	785(19.2)	
Open-window	10755(51.3)	7701(45.6)	3054(74.5)	

SD, standard deviation; BMI, body mass index; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; BFP, body fat percentage; VFI, visceral fat index; <sup>a</sup> Student's t test was used to compare mean difference of normal distributed continuous variables between self-cooking meals using solid and clean fuel groups; <sup>b</sup> Chi-square test was used to test the distributions of categorical variables between self-cooking meals using solid and clean fuel groups; \* Contain missing values.

**Table 2 Estimated independent associations of solid fuel use and smoking with obesity indices**

Variables	Obesity indices, $\beta$ (95% CI)					
	BMI	WC	WHR (%)	WHtR (%)	BFP	VFI
Solid fuel use						
Crude	-0.70(-0.82,-0.58)	-1.61(-1.96,-1.26)	-0.23(-0.49,0.03)	-0.24(-0.47,-0.02)	0.28(0.07,0.49)	-0.35(-0.49,-0.20)
Adjusted <sup>a</sup>	-0.58(-0.71,-0.45)	-1.55(-1.91,-1.19)	-1.01(-1.27,-0.75)	-0.81(-1.04,-0.59)	-0.80(-0.95,-0.64)	-0.64(-0.79,-0.50)
Additional adjustment for smoking status <sup>a</sup>	-0.58(-0.71,-0.46)	-1.56(-1.92,-1.20)	-1.01(-1.27,-0.75)	-0.82(-1.04,-0.59)	-0.80(-0.96,-0.65)	-0.65(-0.79,-0.50)
Smoking						
Crude	-0.63(-0.79,-0.48)	1.75(1.30,2.19)	1.89(1.56,2.22)	-2.14(-2.42,-1.86)	-8.74(-8.98,-8.50)	2.18(2.00,2.37)
Adjusted <sup>b</sup>	-0.67(-0.87,-0.47)	-1.38(-1.95,-0.81)	-0.28(-0.69,0.13)	-0.83(-1.19,-0.47)	-1.03(-1.28,-0.79)	-0.96(-1.18,-0.73)
Additional adjustment for fuel type and kitchen ventilation <sup>b</sup>	-0.68(-0.88,-0.48)	-1.40(-1.97,-0.83)	-0.29(-0.70,0.12)	-0.84(-1.20,-0.48)	-1.04(-1.29,-0.80)	-0.96(-1.19,-0.74)

Linear regression models were used to investigate the independent associations of solid fuel use and smoking with obesity indices. BMI, body mass index; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; BFP, body fat percentage; VFI, visceral fat index. <sup>a</sup> Adjusted for age, sex, marital status, education level, personal monthly income, drinking status, high fat diet, adequate fruit and vegetable intake, physical activity, and kitchen ventilation. <sup>b</sup> Adjusted for age, sex, marital status, education level, personal monthly income, drinking status; high fat diet, adequate fruit and vegetable intake and physical activity.

**Table 3 Estimated independent associations of solid fuel use and smoking with prevalent obesity**

Variables	Prevalent obesity, OR (95% CI)					
	BMI	WC	WHR	WHtR	BFP	VFI
Solid fuel use						
Crude	0.73(0.66,0.80)	0.86(0.80,0.92)	0.98(0.92,1.06)	0.92(0.86,0.99)	1.04(0.96,1.12)	0.88(0.82,0.94)
Adjusted <sup>a</sup>	0.77(0.69,0.85)	0.81(0.75,0.87)	0.81(0.75,0.87)	0.79(0.73,0.86)	0.72(0.66,0.79)	0.76(0.71,0.83)
Additional adjustment for smoking status <sup>a</sup>	0.77(0.69,0.85)	0.81(0.75,0.87)	0.81(0.75,0.87)	0.79(0.73,0.86)	0.72(0.66,0.79)	0.76(0.70,0.83)
Smoking						
Crude	0.76(0.68,0.86)	0.38(0.35,0.42)	0.61(0.56,0.67)	0.60(0.55,0.65)	0.23(0.21,0.25)	2.51(2.30,2.74)
Adjusted <sup>b</sup>	0.71(0.61,0.83)	0.81(0.72,0.91)	0.85(0.75,0.95)	0.77(0.68,0.87)	0.70(0.62,0.79)	0.71(0.63,0.80)
Additional adjustment for fuel type and kitchen ventilation <sup>b</sup>	0.71(0.60,0.83)	0.81(0.71,0.91)	0.85(0.75,0.95)	0.77(0.68,0.86)	0.70(0.62,0.79)	0.70(0.63,0.79)

Logistic regression models were used to investigate the independent associations of solid fuel use and smoking with prevalent obesity. BMI, body mass index; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; BFP, body fat percentage; VFI, visceral fat index. <sup>a</sup> Adjusted for age, sex, marital status, education level, personal monthly income, drinking status, high fat diet, adequate fruit and vegetable intake, physical activity, and kitchen ventilation. <sup>b</sup> Adjusted for age, sex, marital status, education level, personal monthly income, drinking status; high fat diet, adequate fruit and vegetable intake and physical activity.

Figure 1

