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Measurement of temperature, relative humidity and concentrations of CO, CO_2 and TVOC during cooking typical Chinese dishes

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ABSTRACT

This study investigated the effect of exhaust hood during cooking case-study dishes of Eight Cuisines of China. Parameters were measured of hood idle or working mode included the continuous measurements of air temperature, air relative humidity and generations of CO, CO_2 and TVOC of the breathing zone. Different from former researchers, we found the cooking techniques are not the reason that causes serious pollution. The emissions of CO and CO_2 not only were related to the cooking time, but also occurred largely as a result of the burning of the gas; however, the generation of TVOC attributed in large part to using the seasonings, ingredients and the behavior of marinating. The maximum increase of TVOC concentration during cooking dishes with cooking wine was at least 526.7–543% higher than the others. Besides, the behavior of marinating would cause at least 80–556.3% increase. Compared to hood idle mode, the decrement of maximum increases of temperature, CO_2 and TVOC concentrations were 7–50.29%, 6.6–379.5% and 136.6–4211.6% respectively in hood working mode. The situation became very complicated for relative humidity and CO concentration. Even with an exhaust hood, there was still a significant high value of contaminant levels in the breathing zone, especially in the beginning phase of the cooking process (200 s). The values of test parameters finally reached a stable value after a certain period of time. This time of hood idle mode was almost the double of the hood working mode.

1. Introduction

Indoor air quality in Chinese kitchen is poor due to lack of ventilation and poor air circulation. In recent years, concerns over the indoor environment have increased as a result of knowledge about the significance of air quality and thermal conditions on health, comfort and productivity. Great attention should be paid to the indoor conditions in Chinese residential kitchens – when cooking; the housewives are regularly exposed to excessive quantities of pollutant.

China has the maximum population; nearly 1.3 billion in the world and Chinese housewives often spend a long time in the kitchen. Everyday, Chinese's housewives spend 3.4–4 h in the kitchen; it is about 1/4 of their everyday life [1]. In China, unique regional cuisines evolved and gained widespread acceptance, because of China's varying climate, enormous size and topography. There were eight most famous cuisines, which were Jiangsu, Guangdong, Sichuan, Shandong, Fujian, Anhui, Zhejiang and Hunan, which from what is now known as the Eight Cuisines of China. Certainly, many other local cuisines are famous too, such as Shanghai Cuisine and Beijing Cuisine.

The most delicate culinary skills are processed in Chinese kitchen in controlling the degree of cooking (heat, temperature or duration). China's Eight Cuisines all have their own typical characteristics with different but fantastic and mouthwatering flavor. They are as follows:

Sichuan Cuisine: Sichuan Cuisine is one of the most well known Chinese cuisines around the world, both pungent and spicy.
Jiangsu Cuisine: Furthermore, called Huaiyang. Jiangsu Cuisine is famous for carving techniques and a fresh, light and sweet flavor.
Zhejiang Cuisine: It made up of Shaoxing, Ningbo and Hanzhou Cuisines. Zhejiang Cuisine is characterized with mellow fragrance, freshness and tenderness.
Guangdong Cuisine: Guangdong Cuisine is enjoyed for its fresh, light and crisp.
Hunan Cuisine: Hunan Cuisine is famous for a pungent flavor and its use of pepper, chili and shallot.
Fujian Cuisine: Fujian Cuisine is considered by pickled and bright colors. It is a combination of Xiamen, Quanzhou and Fuzhou Cuisine.
Anhui Cuisine: Anhui Cuisine focuses on the cooking temperature, stewing and braising.

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Shandong Cuisine: Shandong Cuisine is considered by an emphasis on aroma, freshness and crispness.

With 24 common cooking techniques, every cuisine can be cooked into 200–300 dishes. During cooking process, a wide range of seasoning is applied [2] and oils are usually first heated at high temperatures in a wok (large metal pans with raised sides). As a result, a quite significant contribution to indoor air pollution is made by the emissions from different styles of cooking operation in China. The emissions include grease particles, vapor, smoke, products of heat, combustion and moisture.

A high concentration of carcinogens was found in the period of cooking. However, none of any carcinogenic compounds such as formaldehyde, acetaldehyde or benzene are detected in the raw fuels, confirming that those are almost entirely derived due to cooking activity alone [3]. The results showed that inhalation of carcinogens generated during cooking may increase the risk of lung cancer among nonsmoker women [4–9]. The efficiency of the exhaust hood was associated with the risk of contracting cancer for non-smoking women [10,11].

Based on measurements, the concentrations of sub-micrometer particles increased 10-times during cooking [12]. Another study [13] showed that deep-frying gave rise to the largest amount of PM2.5 and most chemical components, followed by pan-frying, stir-frying, boiling, and steaming. The particle emission factors also varied significantly according to the type of oil used [14].

Chinese kitchens' environment was reported in a few literatures. Chao's [15] measurements showed that carbon monoxide (CO) concentrations are at highest level during cooking hours in Taiwanese. Individual exposure to NO_2 in residences was tested in Hong Kong by Chao and Law [16]. The study showed that one's exposure to NO_2 has a lot to do with cooking behavior. Chiang [17] and Angui Li [18] investigated indoor air environment in traditional residential and commercial kitchens, respectively. They all focused on the air contaminant distributions, temperature fields and flow fields. The results showed that even there was an exhaust hood; the waste heat still cannot be removed effectively. If the temperature in the space increases by 5.5 °C above the comfort level, the productivity may drop as much as 30% [19]. In California Energy Commission's study, a thermally neutral temperature is 23.9 °C (75 °F) [20]. Chi-ming Lai [21] investigated the design and experimental assessment of side exhaust systems in a full-scale model kitchen. They discovered that the generation of CO_2 occurs largely as a result of the burning of the gas, and has little to do with the cooking behavior. Lee found the operations of pan-frying food and boiling food with soup in a hot pot could generate considerable quantities of air pollutants [22].

The previous studies highlighted the importance of good indoor air quality in the kitchen. However, few of any studies had addressed the issue of how to make improvements to indoor environment in traditional Chinese kitchen.

The use of an efficient kitchen hood is essential to ensure the provision of a healthy, comfortable and energy efficient working environment [23]. ASHRAE Research Project RP-1202 [24] quantified the effect of the exhaust hood's side panels, front overhang, and rear seals on the minimum capture and containment (C&C) rate. Furio [25] conducted an analysis to evaluate the velocity fields induced in the proximity of local exhaust hoods. Kosonen [26] used AirPak 2.0.6 to evaluate the effect of a capture jet on the contaminant removal efficiency of a ventilated ceiling. Kyoungbin and Changhee [27] conducted a 3D numerical analysis to investigate the airflow characteristics in a kitchen with different separation plate shapes.

Up to now, the actual working condition of the exhaust hood of Chinese residential kitchen is still unknown. For example: How much does the contamination generate during cooking process? When does the contamination emit from cooking process? What cooking behavior would cause serious pollution in indoor environment? Is the exhaust hood efficient enough to remove the pollutants?

Oversized ventilation system increases the life-cycle costs to the system and unnecessary energy consumption, while undersized airflow rates would lead to indoor air problems. In order to improve the indoor thermal environment of typical Chinese style kitchen and assessment of exhaust hood during cooking Chinese food, a study was undertaken in a traditional residential kitchen of Xi'an, China to investigate the exhaust hood during cooking the typical dishes of Eight Cuisines of China. Parameters were measured during hood cooking mode, and hood idle mode included the continuous measurements of air temperature, air relative humidity and emissions of CO, CO_2 and TVOC from cooking process of the breathing zone.

Table 1
Geometric specifications of the model kitchen (unit, m).

Case-study kitchen	$3 \times 2.5 \times 2.8$
Cooking bench	$1 \times 2.5 \times 0.8$
Gas fire	$0.7 \times 0.2 \times 0.2$
Exterior window	2×0.9
Interior door	2×0.9

2. Experimental method

2.1. Site selection

Xi'an is one of the most famous Chinese metropolises with more than 7 million populations. So it is a perfect place to investigate the indoor environment in Chinese residential kitchens during cooking. A typical Chinese residential kitchen was selected in May 2012. The residential kitchen is part of a typical middle-sized family apartment building. The apartment building is sited in a street with little traffic where some other apartment buildings are found. No open chimney or other sources of air pollution were noted nearby. The studied hood, range and appliances are the typical type used in Chinese residential kitchens. The geometric data of this case-study kitchen are listed in Table 1.

During cooking, people in China usually close the exterior window in the kitchen to avoid the exhausted air flowing back into the kitchen. To prevent wind from blowing into the kitchen, and making the stove flame flutter, which affects the burning efficiency. The interior door to the kitchen is needs to be closed too. Therefore, the kitchen fumes could not spread into other living spaces, and the noise made by the range hood can be masked. In this experiment, one important reason for closing the window and interior door is for the accurate measurement of the concentration of pollutants. Schematic diagram of the case-study kitchen is presented in Fig. 1. In this study, it was assumed that the primary air would flow from the crack under the interior doors, with a height of 0.02 m from the floor. The front lower edge of the hood of the case-study kitchen overhang is set to the 1.8 m as measured vertically from the finished floor. The hood is commercially available in the market and had a volume flow rate of 0.2 m^3/s. A 2-head stove is equipped in the case-study kitchen, and only the right one was used with a rated heat flux of 4.0 kW. Natural gas was used as cooking fuel.

2.2. Case-study dishes

The dishes prepared in this study covered the major domestic cooking styles in China such as deep-fry (Sweet and Sour Pork and Spring Rolls), stir-fry (Kung Pao Chicken, Stir-Fried Rice Noodles with Beef and Sautéed Minced Shrimps with Mixed Vegetables), steam (Fish Head en Casserole) and boil (Wensi Tofu Soup and Braised Pork). The quantities of foods were designed