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Study on pollution control in residential kitchen based on the push-pull ventilation system

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ABSTRACT

Pollutants generated from cooking process are detrimental to occupant's health. For conventional residential kitchen in hot summer and cold winter region of China, range hood is installed to exhaust oil fume and other pollutants. In typical kitchen, air is supplied through the insect screen. However, this kind of air supply and exhaust system is not capable of providing air distribution for good indoor air quality in kitchen. In order to solve this problem, the combined scheme with air supply through slot air curtain and air exhaust through range hood is proposed, which is termed as the push-pull ventilation system. Both numerical simulation and field test were carried out to investigate the air velocity, temperature and pollutant distributions. Orthogonal study was performed during numerical simulation. Air curtain velocity (A), air curtain angle (B, C, D, E) and exhaust velocity (F) were chosen as six factors during the L_{25} (5^6) orthogonal test. The average CO_2 concentration of the 25 cases in breathing region was compared. It is shown that by using the range hood alone, oil fume generated by cooking cannot be effectively exhausted out of the kitchen. With application of the push-pull ventilation system, the air temperature can be reduced during the summer scenario, which may improve occupant thermal comfort. Meanwhile, the pollutant concentration can be reduced with the improved air distribution. Moreover, the sequence for effect of influencing factors on the pollutant concentration distribution is A>B>C>E>D>F. This proposal provides a scientific support to reduce the indoor pollutant concentration in kitchen.

1. Introduction

Previous studies have provided a positive correlation between the cooking frequency and the lung cancer [1,2]. The number of women smoking in Taiwan is relatively small, but Taiwan has a high prevalence of lung cancer in women [3]. While smoking generally leads to small cell lung cancer and squamous cell carcinoma, the majority of women suffer from lung adenocarcinoma [4,5]. There is an average of 1650–1750 women dying of lung cancer per year in Taiwan, which constitutes one sixth of all female cancer patients [5]. Since most people spend 90% of the time indoors, the indoor environment has a great influence on human health [6]. Oberdorster [7] considers that the major pollutants for causing the lung diseases are ultra-fine particles (referred to as UFPs) with lowest diameter reaching 1 nm. Gao et al. [8] measured the particle size of 0.1–10 μm by laser diffraction analyzer and found that the percentage of particles with size between 0.1 and 1 μm during cooking process was almost 100%. Abdullahi et al. [9] have studied the aerosol mass concentration, particle size distribution and chemical composition in typical kitchen. Results showed that the cooking process can produce a large amount of aerosols, including alkanes, fatty acid, binary carboxylic acid, lactone, polycyclic aromatic hydrocarbons and phytosterol *etc.* Sarigiannis et al. [10] proved that combustion is the main source of carcinogenic polycyclic aromatic hydrocarbons (PAHs). PAHs produced by the cooking contains both the low molecular weight gaseous PAHs and the particulate-phase PAHs. The latter contributes more severe health threat than the benzo[a]pyrene, when the concentration of the particulate-phase PAHs is more than 95% [3]. Small particulate particles are more likely to cause cardiovascular disease because they will easily transport through the blood. Zhang et al. [11] found that lower levels of CO_2 concentration, indoor temperature and relative humidity can effectively alleviate the symptoms of sick building syndrome (SBS). The hot and humid environment in the kitchen

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will affect occupants' thermal comfort and working efficiency. The main factors affecting thermal comfort include air temperature, relative humidity, air velocity and average radiant temperature. Simone et al. [12] conducted a field investigation in several American kitchens. It is shown that the environment in majority of the kitchen is warm-to-hot, thus the standard PMV-PPD index is not suitable for application in kitchens. Chatzidiakou et al. [13] found that indoor air quality can be improved when indoor temperature, humidity and CO_2 concentrations are maintained within the standard-recommended range.

The oil fume produced in kitchen can be discharged outside through the range hood. However, the efficiency of the range hood is related to many factors, including the type of the range hood, air flow velocity, heat production, aerodynamic design and space position [14]. Saha et al. [15] performed experimental and numerical studies to obtain the distribution characteristic of the CO, CO_2 and temperature in four college kitchens in India. They found that the pollutant distribution in kitchen depends on the building structure, object placement position and ventilation type. Gao et al. [16] studied the effect of ventilation type on the efficiency of exhaust hood, and found that the machine working efficiency varies greatly with different conditions of ventilation. Zhang et al. [17] regarded air curtain as an effective means for smoke control, which has been successfully applied to control fire smoke dispersion. Lai [5] conducted an experimental evaluation on a new-type side exhaust system in kitchen to understand how different exhaust configurations affect overall emission performance. It was found that pollution exhaust performances of single-slot, twin-slot, and fence-slot close to the pot rims were quite good, which maintained indoor air quality in the kitchen to be an acceptable level.

Although the above-mentioned studies have considered the influence of air distribution, building structure and space position on the performance of exhaust hood, there are still some issues to be considered further. The mechanism of the pollutant diffusion in kitchen needs further investigation, when both gas and particulate pollutants are concerned. The corresponding cost-effective solution should be given. Ventilation system in typical Chinese kitchen cannot effectively eliminate the indoor pollutants and waste heat [18], which may cause poor indoor air quality and thermal comfort. In this paper, air curtain is proposed as air supply means in kitchen, which forms a new push-pull ventilation system. Both temperature distribution and pollutant dispersion in kitchen were obtained through the experiment. Results are presented to reveal the advantages of the system for pollution control in kitchen.

2. Experiment and test method

Experiment was carried out in the period of May to August in 2015. A kitchen in a residential community located in Nanjing is used as a prototype to build the test rig. The size of the kitchen model is 2.3 m(L) × 1.45 m(W) × 2.4 m(H). To prevent the spread of smoke into other interior spaces, kitchen door is usually closed in Chinese residence. Therefore, during the experiment the door was kept closed, while the window remained open with the installation of the insect screen. In order to ensure the tightness of the kitchen room, tape was used for the air gap at the joint position. Before the implementation of each experimental case, range hood was turned on for 10 min at first. The air in the kitchen was always kept fresh and the influence of the smoke from the previous experimental work was eliminated.

The air curtain device was applied in this paper [19]. Four slots were placed around the gas stove (cooking area). Outside air was sent to the bar-type slots by the blowers through the air duct, a plenum box and other components, which forms the air curtain. The geometry of the kitchen model was shown in Fig. 1. Nine measurement points were placed along an intersection line between the horizontal plane at the height z = 1.5 m (breathing region) and the vertical plane at y = 0.9 m. As shown in Fig. 2(a), the first measurement point was set 0.1 m away from stove. The other eight measurement points were positioned with interval distance 0.1 m, which were denoted as D1-D9 in order. D1 was labeled as an occupant breathing point. The variation of CO_2 concentration with time was recorded. The transient characteristics of temperatures at D1-D9 were measured. In Fig. 2(b), there were eight sampling points, which were labeled as A1-A8. The line connecting these points is the intersection line for the planes with $x = 0.23$ m and $z = 0.86$ m. The latter plane was positioned at the height of the pollutant/heat source. The first sampling point A1 was set 0.03 m away from the pollutant/heat source. The interspace distance between these sampling points was 0.02 m along the negative y-direction. Sampling points A1-A3 were close to the pollutant source, which were within the control area of the air curtain. Sampling points A4 and A5 were above No.1 slot, while A6-A8 were outside of the control range of the air curtain. Pollution control performance by air curtain was studied by analysis of temperature and pollutant concentration at these sampling points through CFD simulation.

2.1. Experimental conditions and measuring instruments

There were three experimental conditions in Table 1, which were recorded as cases E1-E3, respectively. Cooking process was divided into two parts, including frying potato filament and frying Brassica chinensis. There are four stages during the experiment, including the first stage for frying potato filament before 200s, the second stage for flameout between 200s and 300s, the third stage for frying Brassica chinensis between 300s and 500s, and the last stage for turned-off after 500s.

Type K thermocouples with nickel-chromium-silicon were connected with Agilent data acquisition logger, in order to measure

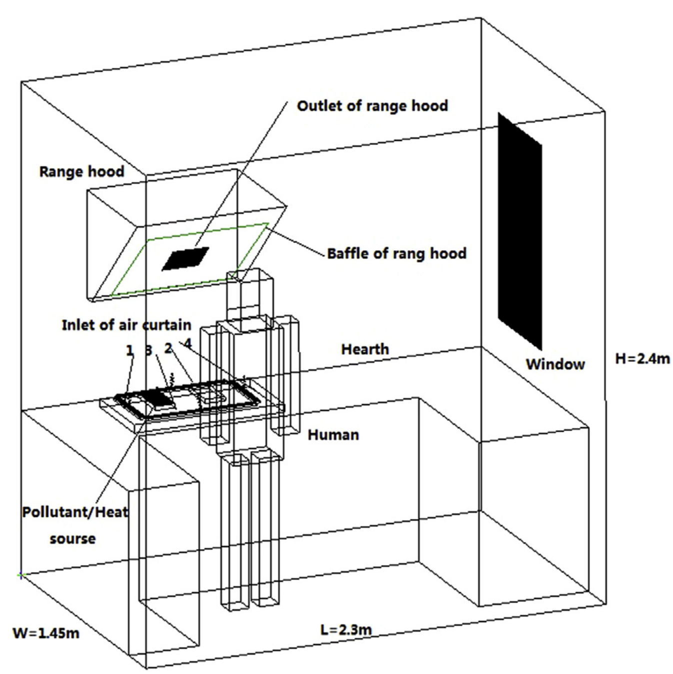

Fig. 1. Schematic diagram of the kitchen model.