Measurement of particle removal performance for a novel design of range hood

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Abstract. A novel range hood (NRH) consisting of a high-efficiency particulate air (HEPA) filter circulation component and exhaust component was designed to improve indoor air quality. The HEPA filter circulation component with an airflow rate of 72 l/s was used to remove the particulate matter generated by cooking activities and return filtered clean air to the room. The exhaust component was used to reject both particulate matter and other indoor air pollutants to the outdoors. Field measurements were carried out in an open kitchen of a two-floor residential house. The total occupied zone was about 160 m² with a living area of 64 m² (including an open kitchen) and a height of 2.5 m. Frying bacon that can generate a large number of particles of different sizes was used to simulate the daily cooking activities. Four operating conditions of the NRH were studied, i.e. 38 l/s exhaust airflow rate with the HEPA circulation on and off, and 78 l/s exhaust airflow rate with the HEPA circulation on and off. The concentration of PM0.1 count, PM2.5 mass, and PM10 mass were measured during measurements. The HEPA filter circulation component of the NRH can dramatically reduce the concentration of all sizes of particles generated by cooking activities. By combining the HEPA filter circulation component, the NRH can separately reduce the concentration of PM0.1, PM2.5, PM10 by up to 91.9%, 95.7%, 94.6% compared to that when only running the exhaust part.

1 Introduction

More and more modern kitchens are located in open areas in residences. Such layout makes effluents produced by normal cooking activities easier to disperse into the occupied zone and the adjoining rooms. The cooking process can release steam, oil droplets, combustion products, and condensed organic pollutants that may worsen indoor air quality in residences [1]. Especially, baking, grilling, frying, etc., can raise the indoor PM1 and PM2.5 concentration level by more than 5 to 90 times higher than normal [2]. In residences, 53.6% of the particulates and 52.5% of personal exposure to microparticles can ascribe to the cooking activities [3]. Previous researches reported that PM1 and chemical compounds generated by cooking or cooking burners can cause respiratory system problems [4, 5].

Local exhaust ventilation (range hood) is an effective method to capture contaminants in residential buildings. To improve the efficiency for capturing contaminants and provide healthier indoor air quality, some innovative technologies had been studied: Aaberg hood [6-12], separation plate technology [13-15], air curtain technology [16-23], tornado-like suction airflow technology [24, 25], and make-up air technology [26-29]. Some optimizations of the range hood have been proposed: Shaping the outlet [30], changing the structure of the fan [31, 32], and adjusting some influential factors (airflow rate, dimension, and burner position of the range hood) [33-36]. Though different methods have been proposed to improve the efficiency for exhausting the contaminants generated by cooking activities, little attention was paid to the waste of thermal energy when exhausting the conditioned indoor air (i.e. the energy used for heating, cooling, humidification, and dehumidification of indoor air).

A novel range hood (NRH) consisting of a high-efficiency particulate air (HEPA) filter circulation component and exhaust component (Fig. 1.) was designed to improve indoor air quality while decreasing the waste of thermal energy. The HEPA filter circulation with an airflow rate of 72 l/s was used to remove particles generated by cooking activities and return the filtered clean air to the room. So that the thermal energy remained in the room. The exhaust system with an airflow rate of 38 l/s and 78 l/s was used to reject both particles and other indoor air pollutants to the outdoors. In this research, field measurements were conducted to test the particle removal performance of the NRH.

Fig. 1. Novel range hood (NRH).

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2 Methods

Field measurements were carried out in an open kitchen of a two-floor residential house. The total occupied zone was about 160 m² with a living area of 64 m² (including an open kitchen) and a height of 2.5 m. The bottom of the NRH was 640 mm above the stove. Measuring instruments were put on the kitchen counter. Measuring sensors were located at the breathing zone of the occupant when cooking in front of the stove, 1500 mm above the floor.

Tracer gas R134a was released and mixed with indoor air by two fans. Multi-gas sampler and analyzer INNOVA 1303 and 1312 were used to measure the tracer gas concentration and the air change rate was calculated by decay method. Frying bacon that generates a large number of particles of different sizes was applied to simulate the daily cooking activities. Four operating conditions of the novel range hood were studied, i.e. 38 l/s exhaust airflow rate with the HEPA circulation on and off, and 78 l/s exhaust airflow rate with the HEPA circulation on and off. The TSI P-Trak Ultrafine Particle Counter 8525 A was used to detect and count PM0.1. The mass concentration of PM2.5 and PM10 were measured by the TSI 3330 Optical Particle Sizer Spectrometer. Each measurement in different scenarios continued for about 10 minutes. The gap between the two measurements was needed to allow the indoor particle concentration level to decrease to the initial non-cooking level and keep stable.

3 Results

3.1 Concentrations of PM0.1 count

Figure 2 shows the concentrations of PM0.1 count measured in four operating conditions. When using 38 l/s and 78 l/s exhaust airflow rate without the HEPA filter circulation, the average concentrations in these two cases were 77393 and 46415 pt/cc respectively. It indicated that the exhaust airflow rate at 78 l/s could reduce the PM0.1 concentration by 40.0% compared to that at the airflow rate of 38 l/s when stopping the HEPA filter circulation. However, in Fig. 2, the higher number concentration level of PM0.1 could be observed even though running the exhaust component at the higher exhaust airflow rate.

The average concentrations of PM0.1 count when using 38 l/s and 78 l/s exhaust airflow rate with the HEPA filter circulation component running were 6304 and 5129 pt/cc, respectively. The higher exhaust airflow rate at 78 l/s could only reduce the PM0.1 concentration by 18.6% when the HEPA filter circulation was on.

Compared to the cases where only the exhaust component was used, combining with the HEPA filter circulation could reduce the PM0.1 concentration by 91.9% and 89.0% at the exhaust airflow rate of 38 l/s and 78 l/s, respectively.

3.2 Concentrations of PM2.5 mass

Figure 3 shows the mass concentrations of PM2.5 measured in four operating conditions. When using 38 l/s and 78 l/s exhaust airflow rates without the HEPA filter circulation, the average concentrations in these two cases were 330.7 and 51.8 μg/m³ respectively. It showed that the increase of the exhaust airflow rate from 38 l/s to 78 l/s could reduce the concentration of PM2.5 by 84.3% when turning off the HEPA filter circulation.

Comparatively, the average mass concentrations of PM2.5 when using 38 l/s and 78 l/s exhaust airflow rate with the HEPA filter circulation running were 14.3 and 13.5 μg/m³, respectively. Only 5.6% concentration was reduced by increasing exhaust airflow rate when the HEPA filter circulation was on.

With the room air recirculated through a HEPA filter, the average mass concentration of PM2.5 at the exhaust airflow of 38 and 78 l/s could be reduced by 95.7% and 73.9%, respectively.
3.3 Concentrations of PM10 mass

Figure 4 shows the mass concentrations of PM10 measured in four operating conditions. When using 38 l/s and 78 l/s exhaust airflow rates without the HEPA filter circulation, the average concentrations in these two cases were 686.7 and 155.9 μg/m³ respectively. It showed that the increase of the exhaust airflow rate from 38 l/s to 78 l/s could reduce the concentration of PM10 by 77.3% with the HEPA filter circulation off.

The average mass concentrations of PM10 when using 38 l/s and 78 l/s exhaust airflow rate with the HEPA filter circulation on were 36.9 and 45.0 μg/m³, respectively. The concentration grew by 18% when increasing the exhaust airflow rate.

With the room air recirculated through a HEPA filter, the average mass concentrations of PM10 at the exhaust airflow of 38 and 78 l/s could be reduced by 94.6% and 71.1%, respectively.

4 Discussion

The counts of particles with a diameter of 5 to 10 μm ranged from 0.04 to 1.03 count/cm³ and the mass concentration of these particles accounted for 27.1% ~ 43.5% of the concentration of PM10 mass. Slight measurement error in counting large particles may result in significant measurement error in concentrations of PM10 mass and reduction rate of PM10.

Increasing the exhaust airflow rate could significantly reduce the concentration of particles. However, it could increase the energy consumption of ventilation. This experiment showed that the air recirculation through a HEPA filter had a very strong effect on indoor air particle removal. Hence, the required exhaust airflow rate for the range hood could be greatly reduced with the help of partial recirculation of airflow through a HEPA filter.

With the partial recirculation of airflow through a HEPA filter, the average mass concentration of PM10 in the room was measured higher at 78 l/s exhaust airflow than that at 38 l/s. It was due to the higher initial concentration of PM10 when starting the measurement at the exhaust airflow rate of 78 l/s, which could be observed from Fig. 4. Fig. 4 shows a clear effect of exhaust airflow on reducing the concentration of PM10 in the test room both with and without using the HEPA filter. However, with the partial recirculation of airflow through the HEPA filter in the range hood, the effect of exhaust airflow was much less.

5 Conclusions

Increasing the exhaust airflow rate can significantly reduce the average concentration of PM2.5 and PM10.

With the room air recirculated through a HEPA filter, the required exhaust airflow rate in a range hood can be greatly reduced.

The air recirculation through the HEPA filter can reduce the average concentration of PM0.1, PM2.5, PM10 by up to 91.9%, 95.7%, and 94.6%, respectively.

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