



# Strategies for Improving Air Quality and Thermal Comfort in Urban Residential Kitchens

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**Abstract.** With the pursuit of better kitchen environments, the problems of air pollution and thermal discomfort in residential kitchens are receiving more and more attention. In order to create healthy and comfortable residential kitchens, in this article, the current status of air quality and thermal environment improvement measures and technologies for residential kitchens are summarized and reviewed from three aspects, namely, improvement and optimization of centralized exhaust shafts in centralized flue exhaust systems, conventional makeup air measures, and cooking zone airflow organization optimization. The results show that adding flow-guide devices to central exhaust shafts, intelligent IoT self-control systems for flue power can improve the problem of poor fume exhaust for users. The air curtain range hood and local supply air around stove (LSAAS) can further enhance thermal comfort by reducing the exposure of air pollutants while decreasing the vertical temperature difference in the kitchen, effectively enhancing the kitchen air quality and improving the thermal environment, and additional air conditioning air supply can further enhance the thermal comfort. It is expected that this paper provides a useful reference for practical engineering to solve the problems of air pollution and thermal discomfort in residential kitchens.

**Keywords:** air pollution, thermal comfort, centralized flue exhaust system, kitchen makeup air, air curtains

## 1 Introduction

The indoor environment has emerged as a prominent concern in recent years, and the kitchen is an important functional area in a residence. However, air quality and thermal comfort in the kitchen are usually worse compared to other areas in the residence, cooking behavior is the main reason.

Both cooking ingredients and fuel combustion generate air pollutants such as CO<sub>x</sub>, NO<sub>x</sub>, VOCs, particulate matter (PM) [1-4]. Long-term exposure to contaminated kitchen environments can negatively affect the health of occupants [5,6]. The centralized flue exhaust system is the most common method of fume exhaust in Chinese residences, Wang

Q et al. [7] surveyed 23,057 samples, of which 69.23% of residences used centralized flue exhaust.

Random selection of range hoods and inconsistent activation times lead to insufficient exhaust power, fume leakage in shafts, user cross-contamination. Lack of kitchen makeup air induces negative pressure, compromising exhaust efficiency<sup>[8,9]</sup>. These issues compromise kitchen air quality. In addition, the high-temperature fumes generated by cooking cause a large vertical temperature gradient in the kitchen, the poor thermal comfort has a significant impact on people's health status, especially for vulnerable populations such as the elderly<sup>[10,11]</sup>.

Therefore, it is of great practical importance to improve kitchen air quality and thermal comfort. In this paper, we will summarize the current status of research on kitchen air quality and thermal environment improvement measures and technologies, aims to provide references and guidelines for the practical works related to kitchen environment improvement.

## 2 Improvement and Optimization of Central Exhaust Shafts

Increasing flue cross-sectional area improves exhaust volume and efficiency, but user concentration in the lower flue reduces these metrics<sup>[12,13]</sup>. Installing the flow-guide devices change the resistance characteristics of central exhaust shaft, reducing the impact of the user's operation rate on the centralized flue exhaust system, increased bottom-user exhaust<sup>[14]</sup>. Zeng L et al. [15] applied the flow-guide device in the centralized flue exhaust system and the exhaust rate of the bottom user can be stabilized at 450 - 550 m<sup>3</sup>/h.

Hybrid can better control the fume exhaust compared to distributed and centralized, providing a fixed mechanical power in addition to the user's range hood, effectively improving the exhaust airflow for each user<sup>[7,16]</sup>. However, there may also be a problem with poor fume exhaust at high operating rates, low operational rates concomitantly result in unnecessary energy expenditure. Internet of Things (IoT) self-control system employs real-time static pressure monitoring in central exhaust shafts to dynamically adjust fan frequencies, effectively mitigating low exhaust volumes in lower floors caused by randomness. Liang Q et al. [17] applied this method, even at high operation rates, this IoT control system was able to achieve more than 500 m<sup>3</sup>/h for the most unfavorable fume exhaust users. It is also 50% more energy efficient than traditional constant frequency roof fan power systems.

## 3 Conventional Makeup Air Strategy

Opening the window is the most convenient way to make up air, However, excessive window airflow will disrupt the heat plume in the cooking area, reducing the capture efficiency of the hood<sup>[18,19]</sup>. Moreover, opening windows in winter causes poor thermal sensation<sup>[20]</sup>.

Naturally powered makeup air through openings in the ceiling or floor can effectively solve the above problems. Wang R [21] applied ceiling makeup air to reduce the

concentration of pollutants in the kitchen by up to 25%. He L et al. [22] experimented that the cumulative number of inhaled particles was reduced by 26% in the ceiling makeup air and 35% in the floor makeup air compared to the window makeup air. However ceiling makeup air may cause a blowing sensation in the upper body areas, causing thermal discomfort in cold winters, but it has a greater enhancement of thermal comfort in kitchens during transitional seasons and summers [20,21]. The ceiling makeup air system offers low investment costs, enables easy retrofitting in existing kitchens, and significantly improves environmental conditions in enclosed kitchens.

## 4 Optimizing Cooking Zone Airflow Organization

### 4.1 Air Curtain Range Hoods

During cooking, the downward air curtain can hinder the thermal plume and air pollutants from escaping into the breathing zone, and also reduce the effect of human walking on the capture efficiency of the range hood, key operational parameters of air curtains include jet velocities typically ranging 0.5–2.5 m/s and discharge angles spanning 0–5° [23–27]. Liu X et al. [27] applied an air curtain range hood with a guide plate, the concentration of escaping cooking fumes could be reduced by a factor of 20,000, the temperature of the human facial region was reduced from 308 K to 301 K, which improved thermal comfort. Lv L et al. [26] utilized an air curtain range hood with 600 m<sup>3</sup>/h exhaust rate and 38.13 m<sup>3</sup>/h makeup flow to achieve pollutant removal effects comparable to conventional range hoods operating at 900 m<sup>3</sup>/h exhaust rate, demonstrating remarkable energy-saving effectiveness.

### 4.2 Local Supply Air Around Stove

An air curtain device is installed around the stove to make up air for the kitchen with the pressure difference between indoor and outdoor can improve the kitchen air quality and thermal environment to a certain extent. Wang R [21] compared the kitchen environment without slit air supply, the CO<sub>2</sub> concentration and temperature in the breathing zone could be reduced by 165 ppm and 17.2°C, respectively. Lu S et al. [28] added door gap ventilation to the LSAAS, creating a displacement ventilation-like effect in the kitchen, which significantly reduced IF.

Jet velocity, second only to exhaust flow rate in impacting pollutant removal efficacy, typically ranges 0.5–1.2 m/s (see Table 1). However, the higher jet velocity under natural power may carry air pollutants from the cooking zone to the human breathing zone [28]. Mechanically-powered systems enable enhanced controllability of air jet velocity [29,30]. Furthermore, LSAAS enhances indoor thermal environment. As demonstrated by Zhou et al. [31], this system maintained superior thermal conditions in kitchens during winter, reducing vertical temperature differences by 0.5 °C. In addition, the integrated air conditioning air supply offers superior pollutant control and thermal comfort [32]. Under equivalent pollutant control, LSAAS achieved higher energy efficiency than conventional exhaust systems, with experiments by Song Yet al. [30] and Liu Y et al. [33] showing 36.3% and 46.7% energy savings respectively.

**Table 1.** Key parameters and performance enhancements of LSAAS

Reference	Exhaust rate (m <sup>3</sup> /h)	Jet velocity (m/s)	Additional ventilation	Improvement effect
Lu S et al. <sup>[28]</sup>	460	0.6	Make-up air through the bottom door gap	94.7% kitchen areas had air age <200s, air exchange efficiency: 39.5%
Liu Y et al. <sup>[29]</sup>	400-500	0.6-1.2	Slot above the stove supply air downwards	PM2.5 in breathing zones dropped 60-83%, capture efficiency up 1.8-14.5%
Zhou B et al. <sup>[31]</sup>	472-483	0.5	/	Capture efficiency rose approximately 7%

## 5 Conclusion

Increasing central exhaust shaft cross-sections enhances fume exhaust; however, non-uniform user distribution in centralized flue systems reduces efficiency, mitigated by flow-guide devices. IoT-based self-control technology dynamically adjusts flue exhaust power, fundamentally resolving low exhaust volume for bottom users caused by stochastic user opening rates and range hood operation states.

Open window ventilation supplements the indoor pressure to improve the range hood exhaust power, but may cause pollutants to spread and form a poor thermal environment, ceiling makeup air and floor makeup air can solve this problem.

Air curtain range hoods and LSAAS form organized airflow, can hinder pollutant leakage, and reduce the vertical temperature difference in the kitchen, effectively improving kitchen air quality and thermal environment.

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## 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.

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