Related Commercial Resources

CHAPTER 31

KITCHEN VENTILATION

KITCHEN ventilation is a complex application of HVAC systems. System design includes aspects of air conditioning, fire safety, ventilation, building pressurization, refrigeration, air distribution, and food service equipment. Kitchens are in many buildings, including restaurants, hotels, hospitals, retail malls, single- and multifamily dwellings, and correctional facilities. Each building type has special requirements for its kitchens, but many basic needs are common to all.

Kitchen ventilation has at least two purposes: (1) to provide a comfortable environment in the kitchen and (2) to enhance the safety of personnel working in the kitchen and of other building occupants. Comfort criteria often depend on the local climate, because some kitchens are not air conditioned. The ventilation system can also affect the acoustics of a kitchen. Kitchen ventilation enhances safety by removing combustion products from gas- or solid-fueled equipment.

The centerpiece of almost any kitchen ventilation system is an exhaust hood, used primarily to remove cooking effluent from kitchens. Effluent includes gaseous, liquid, and solid contaminants produced by the cooking process, and may also include products of fuel and even food combustion. These contaminants must be removed for both comfort and safety; effluent can be potentially life-threatening and, under certain conditions, flammable. The arrangement of food service equipment and its coordination with the hood(s) greatly affect kitchen operating costs.

HVAC system designers are most frequently involved in commercial kitchen applications, in which cooking effluent contains large amounts of grease or water vapor. Residential kitchens typically use a totally different type of hood. The amount of grease produced in residential applications is significantly less than in commercial applications, so the health and fire hazard is much lower.

COOKING EFFLUENT

Effluent Generation

As heat is applied to food in cooking, effluent is released into the surrounding atmosphere. This effluent includes thermal energy (as a convective plume and as heat radiated from the appliance to the kitchen space) that has not transferred to the food, water vapor, and organic material released from the food. The energy source for the appliance, especially if it involves combustion, may release additional contaminants.

All cooking methods release some heat, some of which radiates from hot surfaces, and some that is dissipated by natural convection via a rising **plume** of heated air. The fraction of appliance energy input that is released to form a thermal (convective) plume can vary from approximately 50 to 90%. Typically, most effluent released from the food and the heat source is entrained in this plume, so primary contaminant control is based on capturing and removing the air and effluent that constitute the plume by using exhaust ventilation. However, heat radiated to the space from the appliance is largely unaffected by ventilation and must be addressed by the space air-conditioning system. Chapter 30 of the 2005 *ASHRAE Handbook—Fundamentals* lists typical space heat gain values for many commercial kitchen appliances.

Effluent from five types of commercial cooking equipment has been measured under a typical exhaust hood (Kuehn et al. 1999). Foods that emit relatively large amounts of grease were selected. Figure 1 shows the measured amount of grease in the plume entering the hood above different appliances and the amount in the vapor phase, particles below 2.5 μm in size (PM 2.5), particles less than 10 μm in size (PM 10), and the total amount of particulate grease. Ovens and fryers generate little or no grease particulate emissions, whereas other processes generate significant amounts. However, underfired broilers generate much smaller particulates compared to the griddles and ranges, and these emissions depend on the broiler design. The amount of grease in the vapor phase is significant and varies from 30% to over 90% by mass; this affects the design approach for grease removal systems.

Carbon monoxide (CO) and carbon dioxide (CO_2) emissions are present in solid fuel and natural gas combustion processes but not in processes from electrical appliances. Additional CO and CO_2 emissions may be generated by underfired boilers when grease drippings land on extremely hot surfaces and burn. Nitrogen oxide (NO_x) emissions appear to be exclusively associated with gas appliances and related to total gas consumption.

Figure 2 shows the measured plume volumetric flow rate entering the hood. In general, gas appliances have larger flow rates than electric because additional products of combustion must be vented. Underfired broilers have plume flow rates considerably larger than the other appliances shown. Effluent flow rates from underfired broilers are approximately 100 times larger than the actual volumetric flow rate created by vaporizing moisture and grease from food.

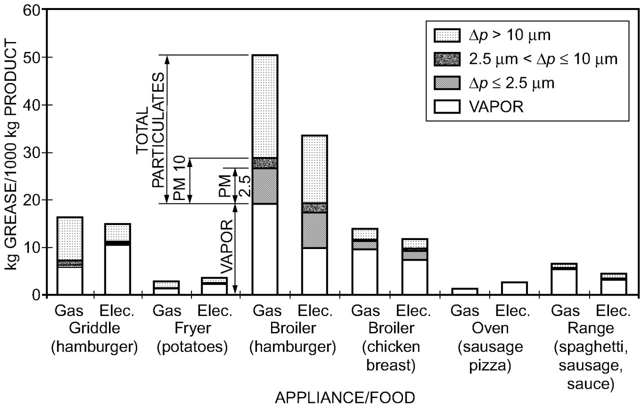


Fig. 1 Grease in Particle and Vapor Phases Emitted by Selected Commercial Cooking Appliances and Food Products
(Kuehn et al. 1999)

The preparation of this chapter is assigned to TC 5.10, Kitchen Ventilation.

The difference is caused by ambient air entrained into the effluent plume before it reaches the exhaust hood.

Thermal Plume Behavior

The most common method of contaminant control is to install an air inlet device (a hood) where the plume can enter it and be conveyed away by an exhaust system. The hood is generally located above or behind the heated surface to intercept normal upward flow. Understanding plume behavior is central to designing effective ventilation systems.

Effluent released from a noncooking cold process, such as metal grinding, is captured and removed by placing air inlets so that they catch forcibly ejected material, or by creating airstreams with sufficient velocity to induce the flow of effluent into an inlet. This technique has led to an empirical concept of **capture velocity** that is often misapplied to hot processes. Effluent (such as grease and smoke from cooking) released from a hot process and contained in a plume may be captured by locating an inlet hood so that the plume flows into it by buoyancy. Hood exhaust rate must equal or slightly exceed plume volumetric flow rate, but the hood need not actively induce capture of the effluent if the hood is large enough at its height above the cooking operation to encompass the plume as it expands during its rise. Additional exhaust airflow may be needed to resist cross currents that carry the plume away from the hood.

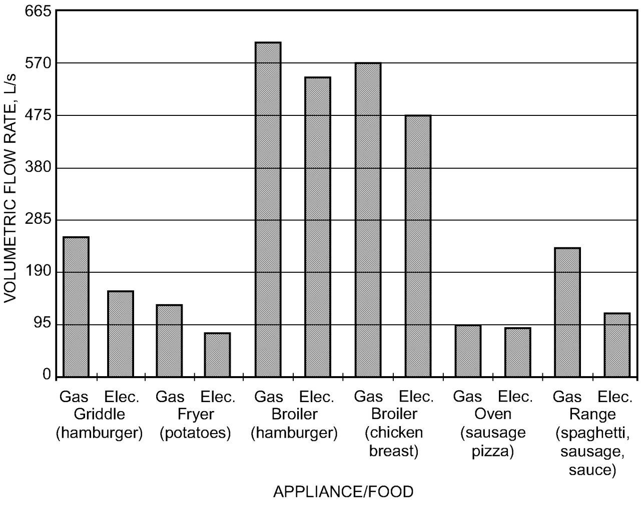


Fig. 2 Plume Volumetric Flow Rate at Hood Entrance from Various Commercial Cooking Appliances

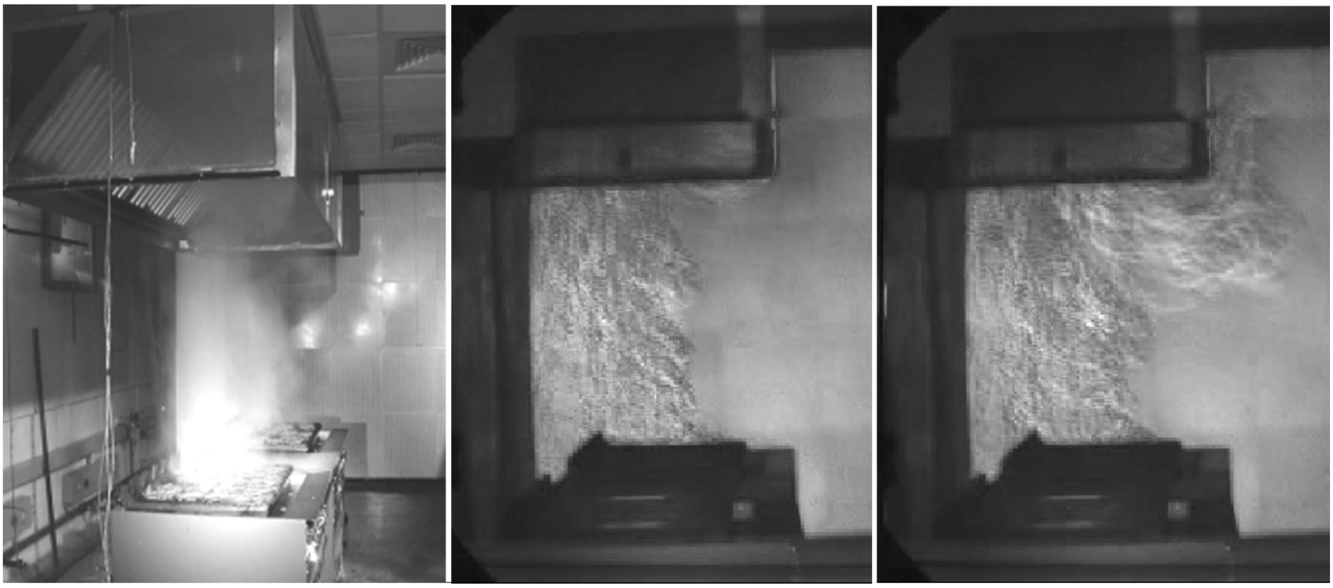
(Kuehn et al. 1999)

A heated plume, without cross currents or other interference, rises vertically, entraining additional air, which causes the plume to enlarge and its average velocity and temperature to decrease. If a surface parallel to the plume centerline (e.g., a back wall) is nearby, the plume will be drawn toward the surface by the **Coanda effect**. This tendency may also help direct the plume into the hood. Figure 3 illustrates a heated plume with and without cooking effluent as it rises from heated cooking appliances. Figure 3A shows two charbroilers cooking hamburgers under a wall-mounted, exhaust-only, canopy hood. Note that the hood is mounted against a clear back wall to improve experimental observation. Figure 3B and 3C show the hot air plume without cooking, visualized using a schlieren optical system, under full capture and spillage conditions, respectively.

EXHAUST HOODS

The design, engineering, construction, installation, and maintenance of commercial kitchen exhaust hoods are controlled by nationally recognized standards [e.g., National Fire Protection Association (NFPA) *Standard* 96] and model codes [e.g., *International Mechanical Code* (IMC; ICC 2006a), *International Fuel Gas Code* (IFGC; ICC 2006b)]. In some cases, local codes may prevail. Before designing a kitchen ventilation system, the designer should identify governing codes and consult the authority having jurisdiction (AHJ). Local authorities with jurisdiction may have amendments or additions to these standards and codes.

Whether a hood is required is determined by the type and quantity of emissions from cooking. Hoods are not typically required



A. TEST SETUP: Two charbroilers under 2.5 m long wall-mounted canopy hood, cooking hamburgers.

B. Schlieren photo of capture and containment at 2075 L/s exhaust rate. Hot, clear air visualization, no cooking.

C. Schlieren photo of spillage and containment at 1550 L/s exhaust rate. Hot, clear air visualization, no cooking.

Fig. 3 Hot-Air Plume from Cooking Appliances under Wall-Mounted Canopy Hood

over electrically heated appliances such as microwave ovens, toasters, steam tables, popcorn poppers, hot dog cookers, coffee makers, rice cookers, egg cookers, holding/warming ovens (ASHRAE *Standard* 154), or heat lamps. Appliances can be unhooded only if the additional heat and moisture loads have been considered in a thorough load calculation and accounted for in the design of the general HVAC system. Temperature and humidity in the kitchen space should be based on recommendations of ASHRAE *Standard* 55.

Hood Types

Many types, categories, and styles of hoods are available, and selection depends on many factors. Hoods are classified by whether they are designed to handle grease; Type I hoods are designed for removing grease and smoke, and Type II are not. Model codes distinguish between grease-handling and non-grease-handling hoods, but not all model codes use Type I/Type II terminology. A Type I hood may be used where a Type II hood is required, but the reverse is not allowed. However, characteristics of the equipment and processes under the hood, and not necessarily the hood type, determine the requirements for the entire exhaust system, including the hood.

A **Type I hood** is used for collecting and removing grease particulate, condensable vapor, and smoke. It includes (1) listed grease filters, baffles, or extractors for removing the grease and (2) fire-suppression system. Type I hoods are required over cooking equipment, such as ranges, fryers, griddles, broilers, and ovens, that produce smoke or grease-laden vapors.

A **Type II hood** collects and removes steam and heat where grease or smoke is not present. It may or may not have grease filters or baffles and typically does not have a fire-suppression system. It is usually used over dishwashers. A Type II hood is sometimes used over ovens, steamers, or kettles if they do not produce smoke or grease-laden vapor and if the AHJ allows it.

Type I Hoods

Categories. Type I hoods fall into two categories: unlisted and listed. **Unlisted hoods** meet the design, construction, and performance criteria of applicable national and local codes and are not allowed to have fire-actuated exhaust dampers. **Listed hoods** are listed in accordance with Underwriters Laboratories, Inc. *Standard* 710. Listed hoods are not generally designed, constructed, or operated in accordance with model code requirements, but are constructed in accordance with the terms of the hood manufacturer's listing, and are required to be installed in accordance with either NFPA *Standard* 96 or the model codes. Model codes include exceptions for listed hoods to show equivalency with the model code requirements.

The two subcategories of Type I listed hoods, as covered by UL *Standard* 710, are exhaust hoods with and without exhaust dampers. UL listings distinguish between water-wash and dry hoods. Also, water-wash hoods with fire-actuated water systems, if investigated for their suitability for fire suppression, are indicated in the UL listing.

All listed hoods are subjected to electrical (if applicable), temperature, and cooking smoke and flare-up (capture) tests. A listed exhaust hood with exhaust damper includes a fire-actuated damper, typically at the exhaust duct collar (and at the replacement air duct collar, depending on the hood configuration). In the event of a fire, the damper closes to prevent fire from entering the duct. Fire-actuated exhaust dampers are permitted only in listed hoods.

Grease Removal. Most grease removal devices in Type I hoods operate on the same general principle: exhaust air passes through a series of baffles that create a centrifugal force to throw grease particles out of the airstream as the exhaust air passes around the baffles. The amount of grease removed varies with baffle design, air velocity, temperature, type of cooking, and other factors. NFPA *Standard* 96 does not allow use of mesh-filter grease removal devices. Additionally, mesh filters cannot meet the requirements of UL *Standard* 1046, and therefore cannot be used as primary grease filters. ASTM *Standard* F2519 provides a test method to determine the grease particle capture efficiency of commercial kitchen filters and extractors. Grease removal devices generally fall into the following categories:

- **Baffle filters** have a series of vertical baffles designed to capture grease and drain it into a container. The filters are arranged in a channel or bracket for easy insertion and removal for cleaning. Each hood usually has two or more baffle filters, which are typically constructed of aluminum, steel, or stainless steel and come in various standard sizes. Filters are cleaned by running them through a dishwasher or by soaking and rinsing. NFPA *Standard* 96 requires that grease filters be listed. Listed grease filters are tested and certified by a nationally recognized test laboratory under UL *Standard* 1046.
- **Removable extractors** (also called **cartridge filters**) have a single horizontal-slot air inlet. The filters are arranged in a channel or bracket for easy insertion and removal for cleaning. Each hood usually has two or more removable extractors, which are typically constructed of stainless steel and contain a series of horizontal baffles designed to remove grease and drain it into a container. Available in various sizes, they are cleaned by running them through a dishwasher or by soaking and rinsing. Removable extractors may be classified by a nationally recognized test laboratory under UL *Standard* 1046, or may be listed as part of the hood construction under UL *Standard* 710. Hoods that are listed with removable extractors cannot have those extractors replaced by other filters.
- **Stationary extractors** (also called a **water-wash hood**), integral to the listed exhaust hoods that use them, are typically constructed of stainless steel and contain a series of horizontal baffles that run the full length of the hood. The baffles are not removable for cleaning, though some have doors that can be removed to clean the extractors and plenum. The stationary extractor includes one or more water manifolds with spray nozzles that, when activated, wash the grease extractor with hot, detergent-injected water, removing accumulated grease. The wash cycle is typically activated at the end of the day, after cooking equipment and fans have been turned off; however, it can be activated more frequently. The cycle lasts 5 to 10 min, depending on the hood manufacturer, type of cooking, duration of operation, and water temperature and pressure. Most water-wash hood manufacturers recommend a water temperature of 55 to 80°C and water pressure of 200 to 550 kPa. Average water consumption varies from 0.1 to 0.3 L/s per linear metre of hood, depending on manufacturer. Most water-wash hood manufacturers provide a manual and/or automatic means of activating the water-wash system in the event of a fire.

  Some water-wash hood manufacturers provide continuous cold water as an option. The cold water runs continuously during cooking and may or may not be recirculated, depending on the manufacturer. Typical cold water usage is 3.5 mL/s linear metre of hood. The advantage of this method is that it improves grease extraction and removal, partly through condensation of the grease. Many hood manufacturers recommend continuous cold water in hoods located over solid-fuel-burning equipment, because the water also extinguishes hot embers that may be drawn up into the hood and helps cool the exhaust stream.
- **Multistage** extractors use two or more stages of filtration to remove a larger percentage of grease. They typically consist of a baffle filter or removable extractor followed by a higher-efficiency filter, such as a packed bead bed. Each hood usually has two or more multistage filters, which are typically constructed of aluminum or stainless steel and are available in standard sizes. Filters are cleaned by running them through a dishwasher or by soaking and rinsing. NFPA *Standard* 96 requires that grease filters be listed, so they must be tested and certified by a nationally recognized test laboratory under UL *Standard* 1046.

UL *Standards* 710 and 1046 do not include grease extraction tests. Historically, grease extraction rates published by filter and hood manufacturers are usually derived from tests conducted by independent test laboratories retained by the manufacturer. Test methods and results therefore have varied greatly.

In 2005, however, ASTM published a new grease filter test standard. ASTM *Standard* F2519 determines the grease particle capture efficiency of both removable filters and fixed extractors such as water-wash hoods. The filters are evaluated by pressure drop as well as particulate capture efficiency. The test generates a controlled quantity of oleic acid particles in size range from 0.3 to 10 μm that are released into a kitchen hood to represent the cooking effluent. The particles are than sampled and counted downstream in the ductwork with an optical particle counter, with and without the extractor in place. The difference in the counts is used to calculate the particulate capture efficiency graphed versus particle size. *Standard* F2519 measures particulate capture efficiency only, not vapor removal efficiency. A more detailed explanation is available in the Exhaust Systems section of this chapter.

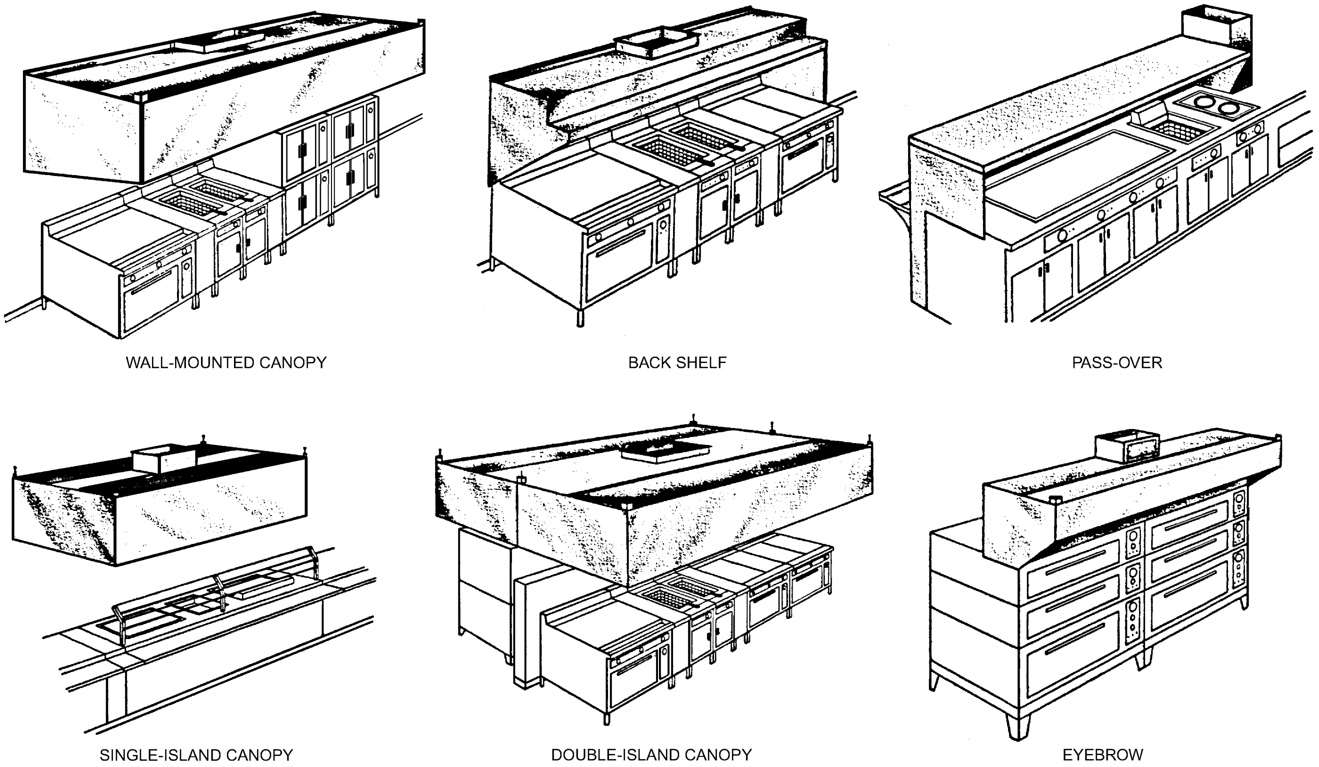
Styles. Figure 4 shows the six basic hood styles for Type I applications. These style names are not used universally in all standards and codes but are well accepted in the industry. The styles are as follows:

- **Wall-mounted canopy,** used for all types of cooking equipment located against a wall.
- **Single-island canopy,** used for all types of cooking equipment in a single-line island configuration.
- **Double-island canopy,** used for all types of cooking equipment mounted back-to-back in an island configuration.
- **Back shelf/proximity,** used for counter-height equipment typically located against a wall, but possibly freestanding.
- **Eyebrow,** used for direct mounting to ovens and some dishwashers.
- **Pass-over,** used over counter-height equipment when pass-over configuration (from cooking side to serving side) is required.

Sizing. The size of the exhaust hood relative to cooking appliances is important in determining hood performance. Usually the hood must extend horizontally beyond the cooking appliances (on all open sides on canopy-style hoods and over the ends on back shelf and pass-over hoods) to capture expanding thermal currents rising from the appliances. For unlisted hoods, size and overhang requirements are dictated by the prevailing code; for listed hoods, by the terms of the manufacturer's listing. **Overhang** varies with hood style, distance between hood and cooking surface, and characteristics of cooking equipment. With back shelf and pass-over hoods, the front of the hood may be kept behind the front of the cooking equipment (**setback**) to allow head clearance for the cooks. These hoods may require a higher front inlet velocity to capture and contain expanding thermal currents. ASHRAE research indicates an appliance front overhang of 230 to 460 mm for canopy style and a 250 mm setback for back shelf/proximity style are preferable to current code minimums. All styles may have full or partial side panels to close the area between appliances and the hood. This may eliminate the side overhang requirement and generally reduces the exhaust flow rate requirement.

Exhaust Flow Rates. Exhaust flow rate requirements to capture, contain, and remove effluent vary considerably depending on hood style, overhang, distance from cooking surfaces to hood, presence and size of side panels, cooking equipment, food, and cooking processes involved. The hot cooking surfaces and product vapors create thermal air currents that are received or captured by the hood and then exhausted. The velocity of these currents depends largely on surface temperature and tends to vary from 0.08 m/s over steam equipment to 0.8 m/s over charcoal broilers. The required flow rate is determined by these thermal currents, a safety allowance to absorb cross-currents and flare-ups, and a safety factor for the style of hood.

Overhang and the presence or absence of side panels help determine the safety factor for different hood styles. Gas-fired cooking


WALL-MOUNTED CANOPY BACK SHELF PASS-OVER

SINGLE-ISLAND CANOPY DOUBLE-ISLAND CANOPY EYEBROW

Fig. 4 Styles of Commercial Kitchen Exhaust Hoods

equipment may require an additional allowance for exhaust of combustion products and combustion air.

Because it is not practical to place a separate hood over each piece of equipment, general practice (reflected in ASHRAE *Standard* 154) is to categorize equipment into four groups, as shown in Table 1.

These categories apply to unlisted and listed Type I hoods. The exhaust volumetric flow rate requirement is based on the group of equipment under the hood. If there is more than one group, the flow rate is based on the heaviest-duty group unless the hood design allows different rates over different sections of the hood.

Though considered obsolete based on laboratory research, some local codes may still require exhaust flow rates for unlisted canopy hoods to be calculated by multiplying the horizontal area of the hood opening by a specified air velocity. Some jurisdictions may use the length of the open perimeter of the hood times the vertical height between hood and appliance instead of the horizontal hood area. Swierczyna et al. (1997) found that these methods of calculation result in higher-than-necessary exhaust flow rates for deeper hoods, because the larger reservoirs of deeper hoods typically increase hood capture and containment performance.

Table 1 Appliance Types by Duty Category

Light duty (200°C)	Electric or gas	Ovens (including standard, bake, roasting, revolving, retherm, convection, combination convection/steamer, conveyor, deck or deck-style pizza, pastry) Steam-jacketed kettles Compartment steamers (both pressure and atmospheric) Cheesemelters Rethermalizers
Medium duty (200°C)	Electric	Discrete element ranges (with or without oven)
	Electric or gas	Hot-top ranges Griddles Double-sided griddles Fryers (including open deep-fat fryers, donut fryers, kettle fryers, pressure fryers) Pasta cookers Conveyor (pizza) ovens Tilting skillets/braising pans Rotisseries
Heavy duty (315°C)	Gas	Open-burner ranges (with or without oven)
	Electric or gas	Underfired broilers Chain (conveyor) broilers Wok ranges Overfired (upright) salamander broilers
Extra-heavy duty (370°C)	Appliances using solid fuel such as wood, charcoal, briquettes, and mesquite to provide all or part of the heat source for cooking.	

Table 2 lists recommended exhaust flow rates by equipment duty category for unlisted hoods and typical design rates for listed hoods. Rates for unlisted hoods are based on ASHRAE *Standard* 154. Typical design rates for listed hoods are based on published rates for listed hoods serving single categories of equipment, which vary from manufacturer to manufacturer. Rates are usually lower for listed hoods than for unlisted hoods, and it is generally advantageous to specify listed hoods. Actual exhaust flow rates for hoods with internal short-circuit replacement air are typically higher than those in Table 2, although net exhaust rates (actual exhaust less internal replacement air quantity) are lower, which seriously compromises the hood's capture and containment performance (Brohard et al. 2003).

Listed hoods are allowed to operate at their listed exhaust flow rates by exceptions in the model codes. Most manufacturers of listed hoods verify their listed flow rates by conducting tests per UL *Standard* 710. Typically, average flow rates are much lower than those dictated by the model codes. Note that listed values are established under draft-free laboratory conditions, and actual operating conditions may compromise listed performance. Thus, manufacturers may recommend design values above their listed values.

Hoods listed in accordance with UL *Standard* 710 cover one or more cooking equipment temperatures: 205, 315, and 370°C. In application, these temperature ratings correspond to duty ratings (see Table 1). The total exhaust flow rate is typically calculated by multiplying the hood air quantity factor by hood length.

ASTM *Standard* F1704 details a laboratory flow visualization procedure for determining the capture and containment threshold of an appliance/hood system. This procedure can be applied to all hood types and configurations operating over any cooking appliances. *Standard* F2474 also provides a laboratory test procedure for determining heat gain of specific combinations of exhaust system, cooking equipment, foods, and cooking processes. Results from a series of interlab heat gain tests (Fisher 1998) have been incorporated in Chapter 30 of the 2005 *ASHRAE Handbook—Fundamentals*.

Appliance Positioning and Diversity

ASHRAE Research Project RP-1202 (Swierczyna et al. 2005) quantified the effect of the position and/or combination of appliances under an exhaust hood on the minimum capture and containment (C&C) exhaust rate. Effects of side panels, front overhang, and rear seal were also investigated. The scope of this laboratory study was to investigate similar and dissimilar appliances under a 3 m wall-mounted canopy hood. The appliances included three full-sized electric convection ovens, three two-vat gas fryers, and three 0.9 m underfired gas broilers, representing the light, medium, and

Table 2 Exhaust Flow Rates by Cooking Equipment Category for Unlisted and Listed Type

	Minimum Exhaust Flow Rate, L/s per linear metre of hood			
Type of Hood	**Light Duty**	**Medium Duty**	**Heavy Duty**	**Extra-Heavy Duty**
Wall-mounted canopy, unlisted	310	465	620	850
listed	230 to 310	310 to 465	310 to 620	540+
Single-island, unlisted	620	775	930	1085
listed	390 to 465	465 to 620	465 to 930	850+
Double-island (per side), unlisted	390	465	620	850
listed	230 to 310	310 to 465	390 to 620	775+
Eyebrow, unlisted	390	390	Not allowed	Not allowed
listed	230 to 390	230 to 390	—	—
Back shelf/proximity/pass-over, unlisted	465	465	620	Not allowed
listed	155 to 310	310 to 465	465 to 620	Not recommended

Source: ASHRAE *Standard* 154.

Table 3 Capture and Containment Exhaust Rates for Three Like-Duty Appliance Lines at Cooking Conditions with Various Front Overhang and Side Panel Configurations under 3 m Wall-Mounted Canopy Hood

	Best Case	Good Case	Worst Case
Three electric full-sized convection ovens	230 mm front overhang full side panels 130 L/(s·m)	230 mm front overhang 170 L/(s·m)	150 mm front overhang 190 L/(s·m)
Three two-vat gas fryers	460 mm front overhang partial side panels 250 L/(s·m)	460 mm front overhang 370 L/(s·m)	150 mm front overhang 510 L/(s·m)
Three gas broilers	300 mm front overhang partial side panels 510 L/(s·m)*	300 mm front overhang 680 L/(s·m)	0 mm front overhang (150 mm cook surface) 790 L/(s·m)

*Adding a rear seal between back of appliance and wall to best-case configuration (150 mm of front overhang and partial side panels) further improved hood performance to an exhaust rate of 1320 L/s [430 L/(s·m)].

Source: Swierczyna et al. (2005).

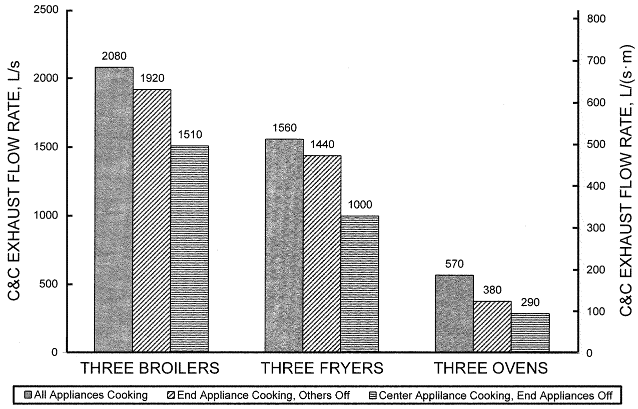


Fig. 5 Exhaust Capture and Containment Rates for One or Three Appliances Cooking from Like-Duty Classes under a 3 m Wall-Canopy Hood

(Swierczyna et al. 2005)

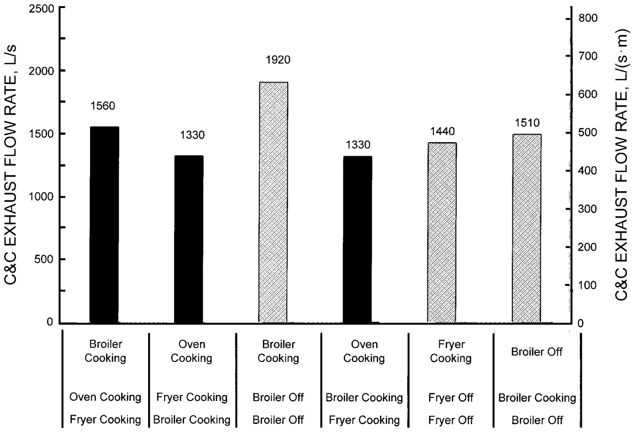


Fig. 6 Capture and Containment Exhaust Rates for Cooking Conditions on Multiduty Appliance Lines (Compared with Single-Duty Lines with Only One Appliance Operating) under 3 m Wall Canopy Hood

(Swierczyna et al. 2005)

heavy-duty appliance categories, respectively. In addition to various physical appliance configurations, appliances were also varied in their usage: either off, at idle conditions, or at cooking conditions. A supplemental study investigated the effect of appliance accessories (including shelving and a salamander) and hood dimensions (including hood height, depth, and reservoir volume) on the minimum exhaust rate required for complete capture and containment.

The study demonstrated that subtle changes in appliance position and hood configuration could dramatically affect the exhaust rates required for complete capture and containment, regardless of appliance duty and/or usage. The wide range in C&C values for a given hood/appliance setup explains why a similar hood installed over virtually the same appliance line may perform successfully in one kitchen and fall short of expectations in another facility. The following conclusions are specific to the conditions tested by Swierczyna et al. (2005).

Airflow Requirements for Like-Duty Appliance Lines. Evaluation supported widely accepted commercial kitchen ventilation (CKV) design practices: higher ventilation rates are required for progressively heavier-duty appliances (Table 3). For a 3 m wall-mounted canopy hood, at a defined median or good-case installation, the light-duty oven line required 520 L/s [170 L/(s·m)], the medium-duty fryer line required 1130 L/s [370 L/(s·m)], and the heavy-duty broiler line required 2075 L/s [680 L/(s·m)] to achieve C&C. Simply increasing front overhang as noted between the worst- and good-case installations in Table 3 reduced the C&C exhaust rate by 10 to 27%. Installing side panels in addition to the increased front overhang (best-case scenario) reduced the exhaust requirements by an additional 18 to 33%.

Diversity in Appliance Usage. Operation diversity was evaluated with cook lines of three similar appliances and included combinations of *cook* and *off* conditions. In most cases, operation correlated directly with the required exhaust rate, with an emphasis on the operation of the end appliances (Figure 5). The capture and containment rate for the end appliance cooking and the other two like-duty appliances off was nearly the same rate as all three appliances cooking.

Changing the condition of end appliances from off to cooking had the greatest effect for medium-duty fryers, which required a 450 L/s increase in the exhaust rate. Because the fryers were thermostatically controlled, they responded to cooking operations by firing the burners. This, combined with an aggressive cooking plume, required a significantly increased exhaust rate for C&C. An aggressive thermal plume was present for the three heavy-duty broilers; the exhaust rate increased 400 L/s. For the light-duty electric convection oven, there was a 95 L/s difference in turning the end appliances from off to cook. Figure 5 also shows that cooking with only the center appliance, with the two end appliances turned off, greatly reduced the exhaust requirement.

Diversity in Appliance Duty and Position (Side-to-Side). The study found that the capture and containment rate of a multiduty appliance line was less than the rate of the heaviest duty appliance in that line, applied over the length of the hood (Figure 6).

Appliance position testing confirmed the exhaust rate of an appliance line was most dependent on the duty of the end appliance. The end appliance drove the exhaust rate more than additional volume from the other two appliances, as they changed from off to

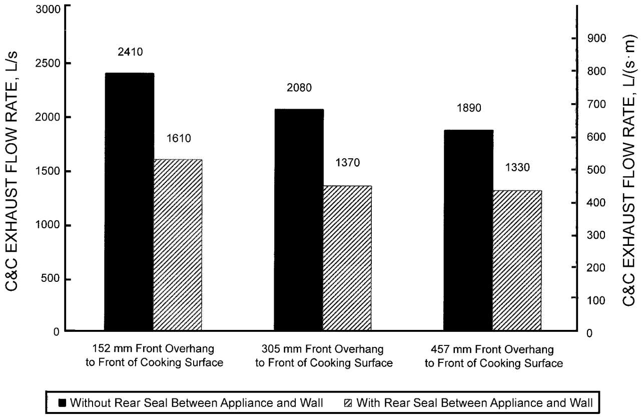


Fig. 7 Capture and Containment Exhaust Rates for Broilers under 3 m Wall Canopy Hood With and Without Rear Appliance Seal at Various Front Overhangs

(Swierczyna et al. 2005)

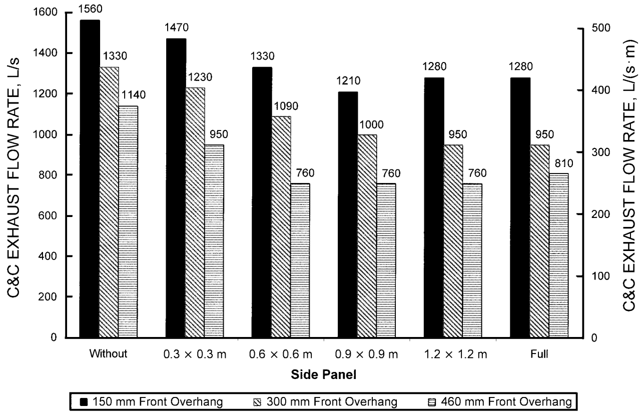


Fig. 8 Exhaust Capture and Containment Rates for Three Two-Vat Gas Fryers with Various Side Panel and Overhang Configurations under 3 m Wall Canopy Hood

(Swierczyna et al. 2005)

cooking conditions or were varied in duty class. In most cases, the lowest exhaust requirements for particular appliance lines were achieved when the lowest-duty appliance was at the end of the appliance line. In other words, hood performance was optimized when the heaviest-duty appliance was in the middle of the appliance line.

Appliance Positioning (Front-to-Back) and Rear Seal. Increasing the front overhang by pushing appliances toward the back wall significantly decreased the required exhaust rates, not only because of the increased distance from the hood to the front of the appliance, but also because of the decreased distance between the back of the appliance and the wall. With a rear seal in place, some of the replacement air, which would have otherwise been drawn up from behind the appliances, was instead drawn in along the perimeter of the hood, helping guide the plume into the hood, as shown in Figure 7.

Hood Side Panels. Side panels installed on the 3 m hood improved hood performance dramatically, by preventing the plume from spilling at the side of the hood and by increasing velocity along the front of the hood. Combining side panels (measuring 0.3 by 0.3 m by 45°, 0.6 by 0.6 m by 45°, 0.9 by 0.9 m by 45°, 1.2 by 1.2 m by 45°, or full) with the maximum hood overhang resulted in the lowest exhaust requirement for all cases tested. The example of the three two-vat gas fryer line is shown in Figure 8.

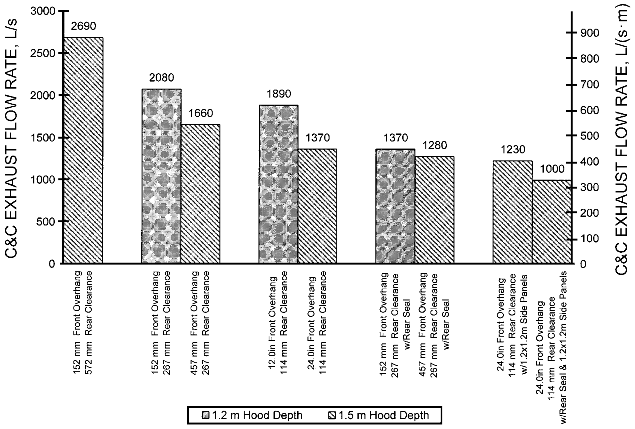


Fig. 9 Exhaust Capture and Containment Rates for a Heavy-Duty Broiler Line under 3 m Wall Canopy Hood with 1.2 and 1.5 m Hood Depths and Front Various Front Overhangs

(Swierczyna et al. 2005)

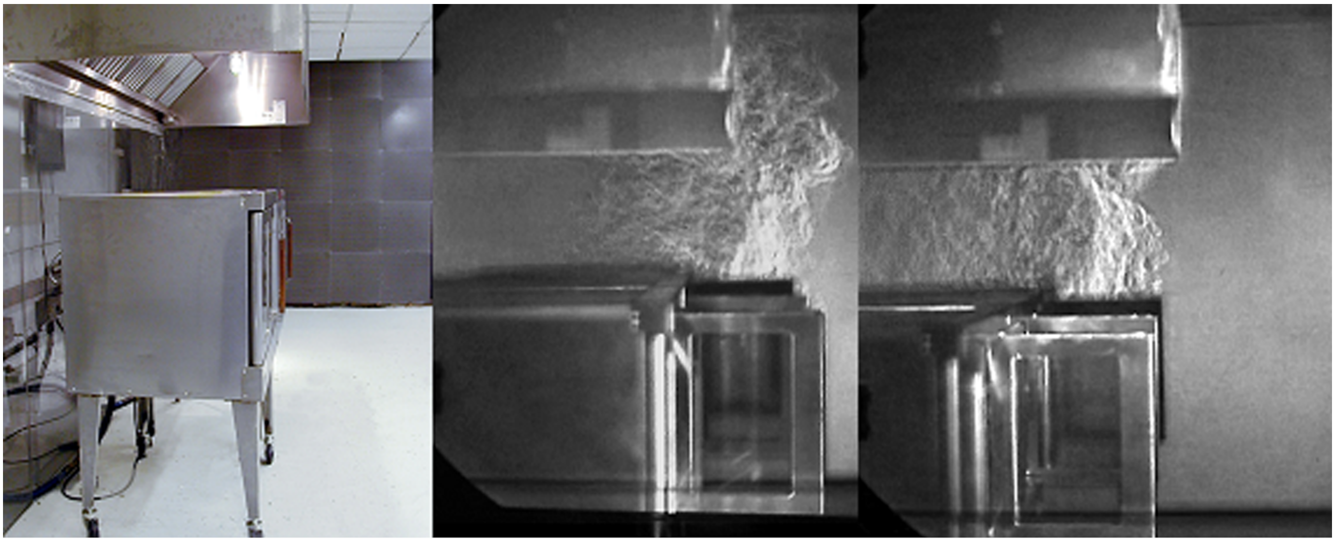
Effect of Shelving on Hood Capture and Containment Performance. Neither solid nor tubular shelving over the six-burner range required an increase in the exhaust rate. In fact, tubular shelving mounted to the back of the appliance showed a slight enhancement compared to having no shelving installed.

Effect of Hood Depth, Reservoir, and Mounting Height on Capture and Containment Performance. Comparing the 1.2 and 1.5 m deep hoods, the deeper hood reduced capture and containment exhaust rates when appliances were positioned with maximum front overhang and minimum rear gap. The deeper hood had a negative effect when appliances remained in the minimum front overhang position. The effect of hood depth in conjunction with front overhang, side panels, and rear seal is shown in Figure 9.

Another advantage of the 1.5 m over the 1.2 m hood was its ability to capture and contain the plume when an oven door was opened. For a 1.2 m hood and a 150 mm front overhang, an exhaust rate of 570 L/s was required for the three electric ovens with the doors closed and 2450 L/s with the doors open. Similarly, for a 1.5 m deep hood with an 460 mm front overhang, 570 L/s was required for three ovens with the doors closed and 1600 L/s with the doors open. The setup and schlieren views are shown in Figure 10.

The reservoir volume of the hood was increased by changing the hood height from 0.6 to 0.9 m. When the broiler was operated in the left appliance position, the increased hood volume marginally improved capture and containment performance. In contrast, a significant improvement was found for the appliance in the center position. This improvement indicated the plume was well located in the hood, and the increased hood volume may have allowed the plume to roll inside the hood and distribute itself more evenly along the length of the filter bank.

Minimizing hood mounting height had a positive affect on capture and containment performance. In most cases, a direct correlation could be made between the required exhaust rate and hood height for a given appliance line. The typical 2 m mounting height (for a canopy hood) was increased to 2.1 to 2.3 m. For the gas broiler installed at the end of the hood, increasing the hood height by 0.3 m required a 14% increase in exhaust. However, when the broiler was in the center position, the increased hood height did not compromise capture and containment performance and required a reduced exhaust rate. The dramatic reduction in the exhaust requirement as the hood-to-appliance distance was reduced below the 2 m mounting height illustrated the potential for optimizing CKV systems by using close-coupled or proximity-style hoods. This effect is shown in Figure 11.



(A) NORMAL VIEW

(B) SCHLIEREN VIEW OF SPILLAGE WITH 1.2 m DEEP HOOD WITH 150 mm OF FRONT OVERHANG

(C) SCHLIEREN VIEW DURING CAPTURE AND CONTAINMENT WITH 1.5 m DEEP HOOD WITH 460 mm OF FRONT OVERHANG

Fig. 10 Three Ovens under Wall-Mounted Canopy Hood at Exhaust Rate of 1600 L/s
(Swierczyna et al. 2005)

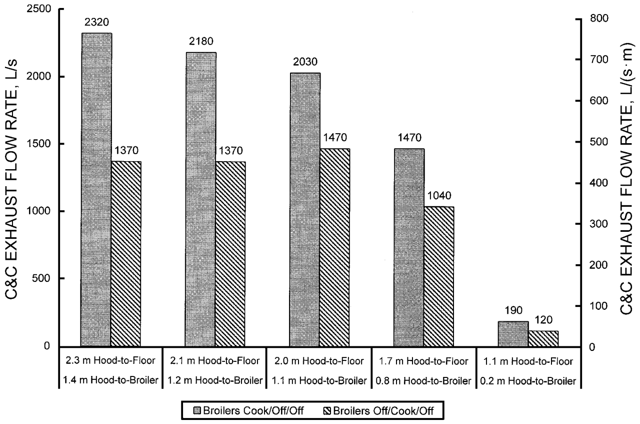


Fig. 11 Exhaust Capture and Containment Rates for Broiler under 3 m Wall Canopy Hood at Various Mounting Heights
(Swierczyna et al. 2005)

Design Guidelines. Swierczyna et al. (2005) illustrated the potential for large variations in the airflow requirements for a specified appliance line and hood configuration. Best-practice design considerations that became evident included the following:

- Position heavy-duty appliances (e.g., broilers) in middle of the line.
- Position light-duty appliances (e.g., ovens) on the end of the line.
- Push back appliances (maximize front overhang, minimize rear gap).
- Seal area between rear of appliance and wall.
- Use side panels, end panels, and end walls.
- Installing shelving or ancillary equipment (e.g., salamander) behind or above a range should not negatively affect C&C performance, if other best practices (e.g., maximizing hood overhang) are observed.
- Use larger hoods, both deeper and taller.
- Installing hoods at lowest height practical (or allowed by code) to minimize distance from cooking surface to hood improves C&C performance.

Table 4 Exhaust Static Pressure Loss of Type I Hoods for Various Exhaust Airflows*

Type of Grease Removal Device	Hood Static Pressure Loss, Pa 230 to 390 L/(s·m)	 390 to 540 L/(s·m)	 540 to 700 L/(s·m)	 700 to 850 L/(s·m)
Baffle filter	60 to 125	125 to 190	190 to 250	250 to 310
Extractor	200 to 340	325 to 425	425 to 750	720 to 1050
Multistage	140 to 275	275 to 425	425 to 720	720 to 1000

*Values based on 500 mm high filters and 7.5 m/s through hood/duct collar.

- Introduce makeup air at low velocity. Do not locate four-way diffusers near hood, and minimize use of air curtains.

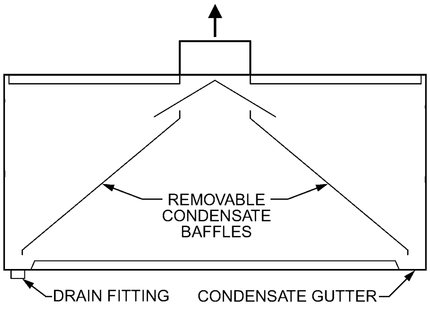
Replacement (Makeup) Air Options. Air exhausted from the kitchen must be replaced. Replacement air can be brought in through traditional methods, such as **ceiling diffusers**, or through systems built as an integral part of the hood. It may also be introduced using low-velocity displacement diffusers or transfer air from other zones. For further information, see the section on Replacement (Makeup) Air Systems.

Static Pressure. Static pressure drop through hoods depends on the type and design of the hood and grease removal devices, size of duct connections, and flow rate. Table 4 provides a general guide for determining static pressure loss depending on the type of grease removal device and exhaust flow rate. Manufacturers' data should be consulted for actual values. Static pressure losses for exhaust ductwork downstream of the hood collar should be calculated for each installation.

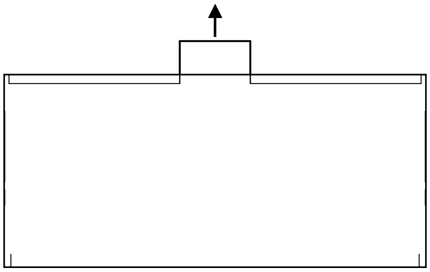
Type II Hoods

Type II hoods (Figure 12) can be divided into the following two application categories:

- **Condensate hood.** For applications with high-moisture exhaust, condensate forms on interior surfaces of the hood. The hood is designed to direct the condensate toward a perimeter gutter for collection and drainage, allowing none to drip onto the appliance below. Flow rates are typically based on 465 to 775 L/(s·m) of hood length. Hood material is usually noncorrosive, and filters are usually installed.



CONDENSATE HOOD



HEAT/FUME HOOD

Fig. 12 Type II Hoods

- **Heat/fume hood.** For hoods over equipment producing heat and fumes only, flow rates are typically based on 155 to 465 L/(s·m) of hood. Filters are usually not installed.

Recirculating Hoods

A recirculating system, previously called a **ductless hood**, consists of a cooking appliance/hood assembly designed to remove grease, smoke, and odor and to return the treated exhaust air directly back into the room. HVAC design must consider that recirculating systems discharge the total amount of heat and moisture generated by the cooking process back into the kitchen space, adding to the cooling load. These hoods typically contain the following components in the exhaust stream: (1) a grease removal device such as a baffle filter, (2) a high-efficiency particulate air (HEPA) filter or an electrostatic precipitator (ESP), (3) some means of odor control such as activated charcoal, and (4) an exhaust fan. NFPA *Standard* 96, Chapter 13, is devoted entirely to recirculating systems and contains specific requirements such as (1) design, including interlocks of all critical components to prevent operation of the cooking appliance if any of the components are not operating; (2) fire extinguishing, including specific nozzle locations; (3) maintenance, including a specific schedule for cleaning filters, ESPs, hoods, and blowers; and (4) inspection and testing of the total operation and interlocks. In addition, NFPA *Standard* 96 requires that all recirculating systems be listed by a testing laboratory. The recognized test standard for a recirculating hood is UL *Standard* 710B. Ductless hoods should not be used over gas-fired or solid-fuel-fired equipment.

Designers should thoroughly review NFPA *Standard* 96 requirements and contact a manufacturer of recirculating hoods to obtain specific information and actual listing test data before incorporating this type of hood into a food service design.

EXHAUST SYSTEMS

Exhaust systems remove effluent produced by appliances and cooking processes to promote fire and health safety, comfort, and aesthetics. Typical exhaust systems simultaneously incorporate fire prevention designs and fire suppression equipment. In most cases, these functions complement each other, but in other cases they may seem to conflict. Designs must balance the functions. For example, fire-actuated dampers may be installed to minimize the spread of fire to ducts, but maintaining an open duct might be better for removing the smoke of an appliance fire from the kitchen.

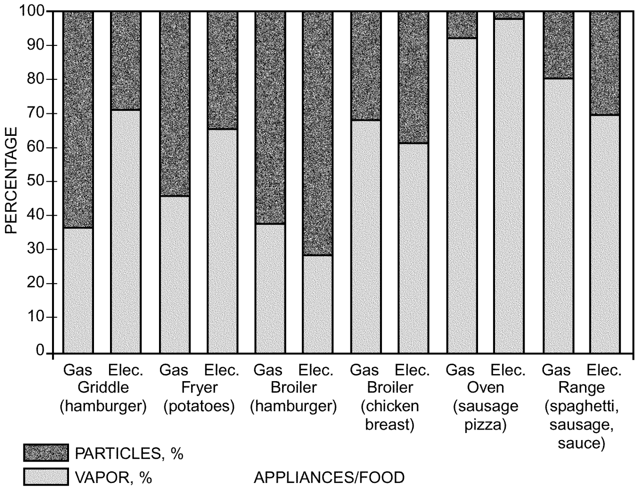


Fig. 13 Particulate Versus Vapor-Phase Emission Percentage per Appliance (Average)

(Gerstler et al. 1998)

Effluent Control

Effluents generated by cooking include grease in particulate (solid or liquid) and vapor states, smoke particles, and volatile organic compounds (VOCs or low-carbon aromatics, which are significant contributors to odor). Effluent controls in the vast majority of kitchen ventilation systems are limited to removing solid and liquid grease particles by mechanical grease removal devices in the hood. More effective devices reduce grease build-up downstream of the hood, lowering the frequency of duct cleaning and reducing the fire hazard. Higher-efficiency grease removal devices increase the efficiency of smoke and odor control equipment, if present.

The reported grease extraction efficiency of mechanical filtration systems (e.g., baffle filters and slot cartridge filters) may not reflect actual performance. These devices are tested and listed for their ability to limit flame penetration into the plenum and duct, not their grease extraction performance. Research indicates that particulate grease consists of small, aerodynamic particles that are not easily removed by centrifugal impingement, as used in most grease extraction devices (Kuehn et al. 1999). If these particles must be removed, a particulate removal unit is typically added, which removes a large percentage of the grease that escaped the grease removal device in the hood, as well as smoke particles.

ASHRAE Research Project RP-745 (Gerstler et al. 1998) found that a significant proportion of grease effluent may be in vapor form (Figure 13), which is not removed by centrifugal means. Mechanical extraction is not effective in removing vapor.

Grease Extraction

Air quality, fire safety, labor cost, and maintenance costs are important concerns about emissions from a commercial cooking operation. Cooking emissions have also been identified as a major component of smog particulate. This has led to regulation in some major cities, requiring reduction of emissions from specific cooking operations.

In a fire, grease deposits in ductwork act as fuel. Reducing this grease can help prevent a small kitchen fire from becoming a major structural fire. In the past, the only control of grease build-up in exhaust ducts was frequent duct cleaning, in which is expensive and disruptive to kitchen operation. It also depends on frequent duct inspections and regular cleaning. Grease build-up on fans, fire noz-

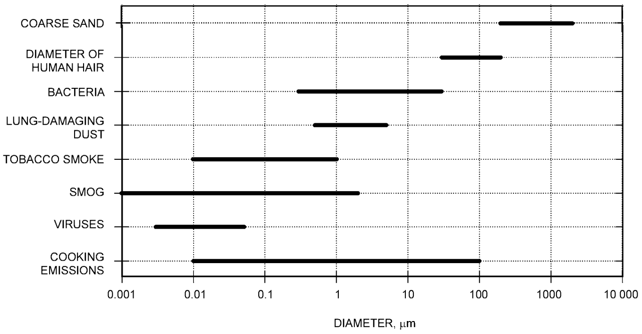


Fig. 14 Size Distribution of Common Particles

zles, roofs, and other ventilation equipment can be costly in additional maintenance and replacement costs.

Effluents generated by cooking include grease in particulate and vapor states, smoke particulate, volatile organic compounds (VOCs), and gases (see the section on Effluent Generation). *Grease particulate* is defined as liquid or solid particles that have become suspended in the air; it can range in size from 0.01 to 100 µm. *Grease vapor* refers to gaseous grease that is dispersed into the air when grease is heated. Vapor is at the molecular scale, much smaller than grease particulate. Grease vapor is condensable and may condense into grease particulate in the exhaust airstream when diluted with room-temperature air or when it is exhausted into the cooler outdoor atmosphere.

Particulate down to 10 µm can be filtered out of the airstream. However, vapor and gases cannot be filtered out of an airstream. In theory, this means that most grease particulate could be filtered out of the exhaust, although this is almost never the case. Figure 14 compares the size of particles from kitchen exhaust to common items. In the range of grease particulate size (0.01 to 100 µm), emissions contain different amounts of particulate at different sizes. These quantities at different sizes can be measured and graphed to create a profile of the particulate emissions. Grease particulate larger than 18 to 20 µm is too heavy to remain airborne and drops out of the airstream.

Every combination of cooking process, food product, cooking equipment, and cooking temperature creates a different profile of particles. These profiles change during cooking, as well. The initial drop of French fries into a fryer gives off a short blast of large particles. Cooking a hamburger gives off a continuous stream of particles and vapors, until it is turned: then a large surge of particles, vapors, and gases are given off. If this is on a broiler, the grease that comes off the hamburger tends to burn and emit very small particles.

Variations in the food product itself change the emissions of a cooking process. Hamburger that is 23% fat content produces more grease than a 20% fat content burger. Chicken breast may have a different effluent characteristic than chicken legs or thighs. Even cooking chicken with or without the skin changes the properties of emissions.

Figures 15 and 16 show typical particle emission profiles for a gas griddle and gas charbroiler both cooking hamburgers (Kuehn et al. 1999).

Effluent controls in the majority of today's kitchen ventilation systems are limited to removal of solid and liquid grease particles by mechanical grease removal devices in the hood. These devices cannot remove vapors or gases. Grease removal devices may be tested and listed under UL *Standard* 1046 for their ability to limit flame penetration into the plenum and duct, but not their grease extraction performance. The claimed grease extraction efficiency of mechanical filtration systems (e.g., baffle filters and slot cartridge filters) may not reflect performance in the field.

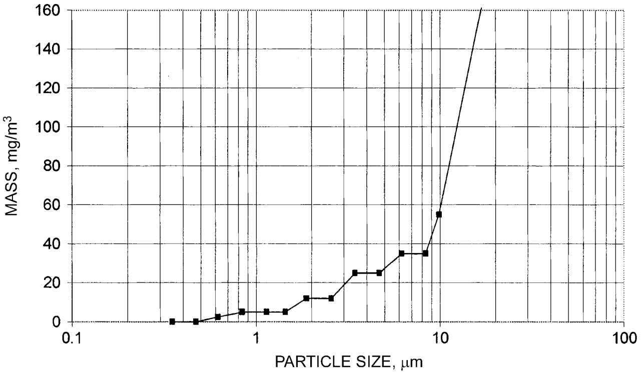


Fig. 15 Gas Griddle Mass Emission Versus Particle Size
(Kuehn et al. 1999)

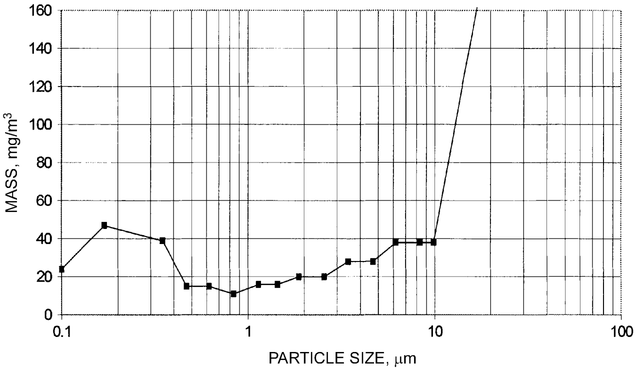


Fig. 16 Gas Charbroiler Mass Emission Versus Particle Size
(Kuehn et al. 1999)

In the past there was no accepted test for evaluating grease removal efficiency for commercial kitchen ventilation in the United States. Those that did exist failed to account for the distribution of particle sizes and vapor.

Filters and grease removal devices can very seldom be given a single meaningful efficiency number, because a filter has different efficiencies for different sizes of particles, flow rates, and phases of particles. A filter that is 90% efficient at removing 10 µm particles may only be 75% efficient at removing 5 µm particles.

ASTM *Standard* F2519-05 can be used to determine fractional filter efficiency for grease particulate. A fractional efficiency curve is a graph that gives a filter's efficiency of over a range of particle sizes. Fractional efficiency curves are created by subjecting a test filter to a controlled distribution of particles and measuring the quantity of particles at each given size before and after the filter. The amount of reduction of particles is used to calculate the efficiency at each given size. The fractional efficiency curve for a typical 510 by 510 mm baffle filter tested at 540 L/(s·m) is shown in Figure 17.

Extraction efficiencies must be compared at the same airflow per linear length of filter or hood. This gives a consistent way of comparing performance of extraction devices that may be built very differently, such as hoods with removable extractors and with stationary extractors. This is also consistent with the way exhaust flow rates for hoods are commonly specified. The airflow rate through a hood changes hood efficiency by changing the velocity at which the air travels through a filter.

To demonstrate what a filter fractional efficiency means with an actual cooking process, the charbroiler emissions curve and the baffle filter efficiency curve have been plotted on one graph in Figure 18. The area under each emission curves is representative of the

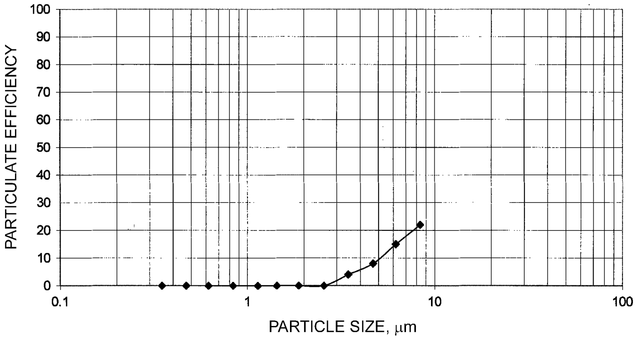


Fig. 17 Baffle Filter Particle Efficiency Versus Particle Size
(Kuehn et al. 1999)

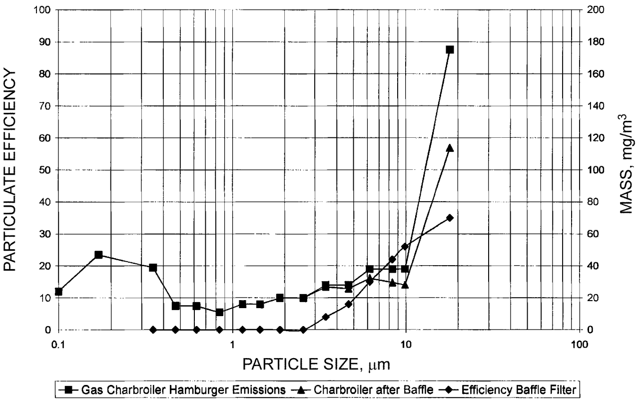


Fig. 18 Particle Efficiency Versus Particle Size
(Kuehn et al. 1999)

total particulate emissions for the charbroiler. As can be seen by comparing the graph before and after the baffle filter, there is very little reduction in the amount of grease exhausted to the ductwork. The area under the "charbroiler after baffle" curve represents the amount of grease particulate exhausted into the ductwork.

The graphs and efficiencies shown here are only for particulate grease. There is also a vapor component of the grease that is exhausted, which cannot be removed by filtration. Some of the vapor condenses and is removed as particulate before reaching the filter. Some condenses in the duct and accumulates on the ductwork and fan. However, with elevated temperatures in the exhaust airstream, vapor may pass through and exit to the atmosphere.

Currently, fractional efficiency data exist for very few extraction devices, but soon many filter and hood manufacturers may be able to supply data for their products.

Higher efficiency at a specific particle size is not the only goal. The ultimate goal is to be able to remove the smallest particles and vapor from the airstream. Smaller particles can only be removed by moving the efficiency curve towards the left. The smaller the particle size, the harder it is to remove.

More effective devices reduce grease build-up downstream of the hood, lowering the frequency of duct cleaning and reducing the fire hazard. Higher-efficiency grease removal devices in the hood reduce maintenance of smoke and odor control equipment, if present.

Concerns about air quality also emphasize the need for higher-efficiency grease extraction from the exhaust airstream than can be provided by filters or grease extractors in exhaust hoods. Cleaner exhaust discharge to outside may be required by increasingly stringent air quality regulations or where the exhaust discharge configuration is such that grease, smoke, or odors in discharge would create a nuisance. In some cases, exhaust air is cleaned so that it can be discharged inside (e.g., through recirculating systems). Several systems have been developed to clean the exhaust airstream, each of which presents special fire protection issues.

Where odor control is required in addition to grease removal, activated charcoal, other oxidizing bed filters, or deodorizing agents are used downstream of the grease filters. Because much cooking odor is gaseous and therefore not removed by air filtration, filtration upstream of the charcoal filters must remove virtually all grease in the airstream to prevent grease build-up on the charcoal filters.

The following technologies are available and applied to varying degrees for control of cooking effluent. They are listed by order of use in the exhaust stream after a mechanical filtration device, with particulate control upstream of VOC control. After the description of each technology are qualifications and concerns about its use. There is no consensus test protocol for evaluating these technologies in kitchen applications.

Electrostatic precipitators (ESPs). Particulate removal is by high-voltage ionization, then collection on flat plates.

- Condensed grease can block airflow, especially when mounted outside.
- As the ionizer section becomes dirty, efficiency drops because the effective ionizer surface area is reduced.
- Under heavy loading conditions, the unit may shut down because of voltage drop.

Ultraviolet (UV) destruction. The system uses ultraviolet light to chemically convert the grease into an inert substance and ozone. Construction (not performance) is tested in accordance with UL *Standard* 710C.

- Requires adequate exposure time for chemical reactions.
- Personnel should not look at light generated by high-intensity UV lamps.
- Exhaust fans should operate when UV lights are on because some forms of UV generate ozone.
- UV is more effective on very small particles and vapor.
- The required frequency of duct cleaning is reduced.
- Lamps need to be replaced periodically; as lamps become dirty, efficiency drops.

Water mist, scrubber, and water bath. Passage of the effluent stream through water mechanically entraps particulates and condenses grease vapor.

- High airflow can reduce efficiency of water baths.
- Water baths have high static pressure loss.
- Spray nozzles need much attention; water may need softening to minimize clogging.
- Drains tend to become clogged with grease, and grease traps require more frequent service. Mist and scrubber sections need significant length to maximize exposure time.

Pleated, bag, and HEPA filters. These devices are designed to remove very small particles by mechanical filtration. Some types also have an activated-carbon face coating for odor control.

- Filters become blocked quickly if too much grease enters.
- Static loss builds quickly with extraction, and airflow drops.
- Almost all filters are disposable and very expensive.

Activated-carbon filters. VOC control is through adsorption by fine activated charcoal particles.

- Require a large volume and thick bed to be effective.
- Are heavy and can be difficult to replace.
- Expensive to change and recharge. Many are disposable.
- Ruined quickly if they are grease-coated or subjected to water.
- Some concern that carbon is a source of fuel for a fire.

Oxidizing pellet bed filters. VOC and odor control is by oxidation of gaseous effluent into solid compounds.

- Require a large volume and long bed to be effective.
- Are heavy to handle and can be difficult to replace.
- Expensive to change.
- Some concern about increased oxygen available in fire.

Incineration. Particulate, VOC, and odor control is by high-temperature oxidation (burning) into solid compounds.

- Must be at system terminus and clear of combustibles.
- Are expensive to install with adequate clearances.
- Can be difficult to access for service.
- Very expensive to operate.

Catalytic conversion. A catalytic or assisting material, when exposed to relatively high-temperature air, provides additional heat adequate to decompose (oxidize) most particulates and VOCs.

- Requires high temperature (230°C minimum).
- Expensive to operate due to high temperature requirement.

Duct Systems

Exhaust ductwork conveys exhaust air from the hood to the outside, along with any grease, smoke, VOCs, and odors that are not extracted from the airstream along the way. This ductwork may also be used to exhaust smoke from a fire. To be effective, ductwork must be greasetight; it must be clear of combustibles, or combustible material must be protected so that it cannot be ignited by a fire in a duct; and ducts must be sized to convey the volume of airflow necessary to remove the effluent.

Model building codes, such as the IMC (ICC 2006a), and standards, such as NFPA *Standard* 96, set minimum air velocity for exhaust ducts at 2.5 m/s. Maximum velocities are limited by pressure drop and noise and typically do not exceed 12.5 m/s. Until recently, NFPA *Standard* 96 and the IMC set the minimum air velocity through the duct at 7.5 m/s. However, based on ASHRAE research (Kuehn 2000) that indicated that there is no basis for specifying 7.5 m/s minimum duct velocity for commercial kitchen ventilation, NFPA and IMC requirements were changed to 2.5 m/s. This allows flexibility for design of variable-speed exhaust systems and retrofitting older systems, though current design practice for new single-speed systems generally continues to use design duct velocity between 7.5 and 9 m/s.

Ductwork should have no traps that can hold grease, which would be an extra fuel source in the event of a fire, and ducts should pitch toward the hood or an approved reservoir for constant drainage of liquefied grease or condensates. On long duct runs, allowance must be made for possible thermal expansion because of fire, and the slope back to the hood or grease reservoir must conform to local code requirements.

Single-duct systems carry effluent from a single hood or section of a large hood to a single exhaust termination. In multiple-hood systems, several branch ducts carry effluent from several hoods to a single master duct that has a single termination. See the section on Multiple-Hood Systems for more information.

Ducts may be round or rectangular. Standards and model codes contain minimum specifications for duct materials and construction, including types and thickness of materials, joining methods, and minimum clearance of 460 mm to combustible materials. Listed factory-built modular grease duct systems are available as an alternative to code-prescribed welded systems. These listed systems typically incorporate stainless steel liners and double-wall, insulated construction, allowing reduced clearances to combustibles and nonwelded joint construction.

When fire-rated enclosures are required for grease ducts, either fired-rated enclosures are built around the duct or the newer listed, field-applied grease duct enclosures can be used directly on the grease duct, or the newer listed, factory-built, modular grease ducts with insulated construction can be used as an integral fire-rated enclosure. Most of these listed systems allow zero clearance to combustibles and also provide a 2 h fire resistance rating, and can be used in lieu of a fire-rated enclosure required in NFPA *Standard* 96 and IMC (ICC 2006a).

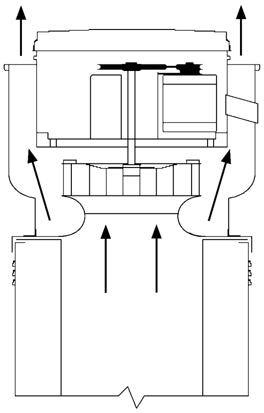


Fig. 19 Power Roof Ventilator (Upblast Fan)

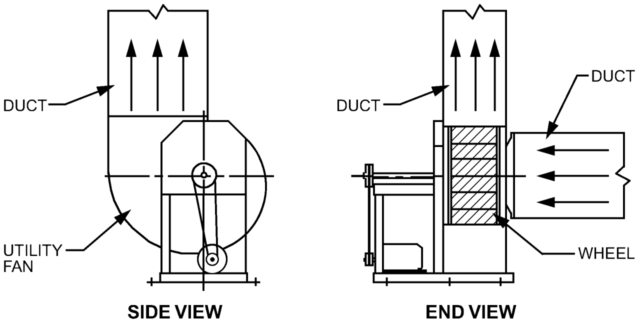


Fig. 20 Centrifugal Fan (Utility Set)

Types of Exhaust Fans

Exhaust fans for kitchen ventilation must be capable of handling hot, grease-laden air. The fan should be designed to keep the motor out of the airstream and should be effectively cooled to prevent premature failure. To prevent roof damage, the fan should contain and properly drain all grease removed from the airstream.

The following types of exhaust fans are in common use (all have centrifugal wheels with backward-inclined blades):

- **Power roof ventilator (PRV).** Also known as **upblast** fans, PRVs are designed for mounting at the exhaust stack outlet (Figure 19), and discharge upward or outward from the roof or building. Aluminum upblast fans must be listed for the service in compliance with UL *Standard* 762, and must include a grease drain, grease collection device, and integral hinge kit to permit access for duct cleaning.
- **Centrifugal fan.** Also known as a **utility set**, this is an AMCA Arrangement 10 centrifugal fan, including a field-rotatable blower housing, blower wheel with motors, drives, and often a motor/drive weather cover (Figure 20). These fans are typically constructed of steel and roof-mounted. Where approved, centrifugal fans can be mounted indoors and ducted to discharge outside. The inlet and outlet are at 90° to each other (single width, single inlet), and the outlet can usually be rotated to discharge at different angles around a vertical circle. The lowest part of the fan must drain to an approved container. When listed in accordance with UL *Standard* 762, a grease drain, grease collection device, and blower housing access panel are required.

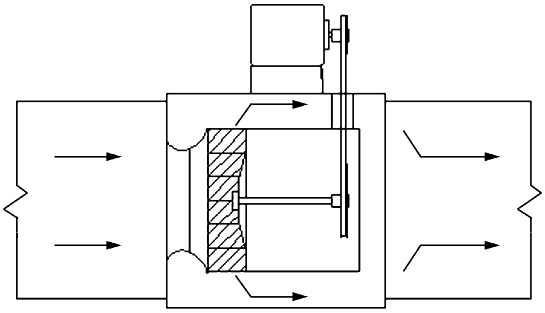


Fig. 21 Tubular Centrifugal (Inline) Fan

- **Tubular centrifugal.** These fans, also known as **inline** fans, have the impeller mounted in a cylindrical housing discharging the gas in an axial direction (Figure 21). Where approved, these fans can be located in the duct run inside a building if exterior fan mounting is not practical for wall or roof exhaust. They are always constructed of steel. The gasketed flange mounting must be greasetight yet removable for service. The lowest part of the fan must drain to an approved container. When listed in accordance with UL *Standard* 762 a grease drain, grease collection device, and blower housing access panel are required.

Exhaust Terminations

Rooftop. Rooftop terminations are preferred because discharge can be directed away from the building, the fan is at the end of the system, and the fan is accessible. Common concerns with rooftop terminations are as follows:

- Exhaust system discharge should be arranged to minimize reentry of effluent into any fresh-air intake or other opening to any building. This requires not only separating the exhaust from intakes, but also knowledge of the direction of the prevailing winds. Some codes specify a minimum distance to air intakes.
- In the event of a fire, neither flames, radiant heat, nor dripping grease should be able to ignite the roof or other nearby structures.
- All grease from the fan or duct termination should be collected and drained to a remote closed container to preclude ignition.
- Rainwater should be kept out of the exhaust system, especially out of the grease container. If this is not possible, then the grease container should be designed to separate water from grease and drain the water back onto the roof. Figure 22 shows a rooftop utility set with a stackhead fitting, which directs exhaust away from the roof and minimizes rain penetration. Discharge caps should not be used because they direct exhaust back toward the roof and can become grease-fouled.

Outside Wall. Wall terminations are less common today but are still occasionally used in new construction. The fan may or may not be the terminus of the system, located on the outside of the wall. Common concerns with wall terminations are as follows:

- Discharge from the exhaust system should not be able to enter any fresh-air intake or other opening to any building.
- Adequate clearance to combustibles must be maintained.
- To avoid grease draining down the side of the building, duct sections should pitch back to the hood inside, or a grease drain should be provided to drain grease back into a safe container inside the building.
- Discharge must not be directed downward or toward any pedestrian areas.
- Louvers should be designed to minimize their grease extraction and to prevent staining of the building facade.

Recirculating Hoods. With these units, it is critical to keep components in good working order to maintain optimal performance. Otherwise, excessive grease, heat, and odors will accumulate in the premises.

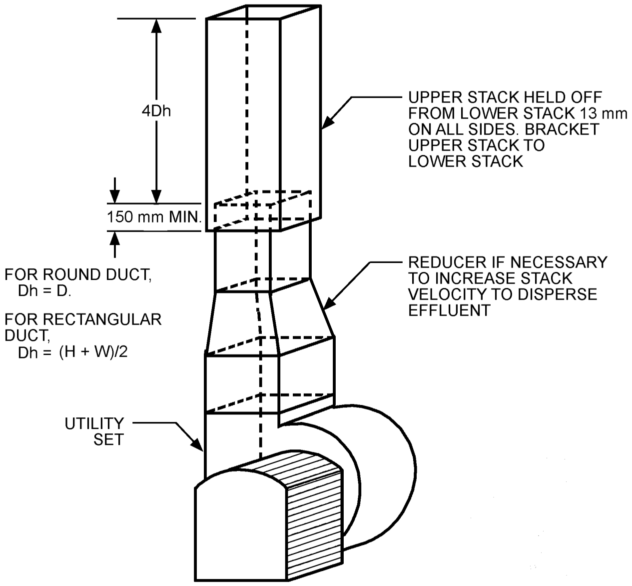


Fig. 22 Rooftop Centrifugal Fan (Utility Set) with Vertical Discharge

As with other terminations, containing and removing grease and keeping the discharge as far as possible from combustibles are the main concerns. Some units are fairly portable and could be set in an unsafe location. The operator should be made aware of the importance of safely locating the unit. These units are best for large, unconfined areas with a separate outside exhaust to keep the environment comfortable.

REPLACEMENT (MAKEUP) AIR SYSTEMS

In hood systems, where air exhausted through the hood is discharged to the outside, the volume of air exhausted must be replaced with uncontaminated outside air. Outside air must be introduced into the building through properly designed replacement air systems. Proper replacement air volume and distribution allow the hood exhaust fan to operate as designed and facilitate proper building pressurization, which is required for safe operation of direct-vent gas appliances (such as water heaters), preventing kitchen odors migrating to adjacent building spaces, and maintaining a comfortable building environment. Proper pressurization enhances the building environment by preventing suction of unfiltered and/or unconditioned outside air into the building envelope through doors, windows, or air handlers. IMC (ICC 2006a) requires neutral or negative pressurization in rooms with mechanical exhaust. NFPA *Standard* 96 requires enough replacement air to prevent negative pressures from exceeding 5 Pa, which may still be excessive for proper drafting of some direct vent appliances. To ensure pressure control, IMC also requires electrical interlock between exhaust and replacement air (makeup) sources. This electrical interlock prevents excessive negative or positive pressures created by the exhaust fan or replacement air unit operating independently.

Indoor Air Quality

Traditionally, the primary purpose of replacement air has been to ensure proper operation of the hood. Kitchen thermal comfort and indoor air quality (IAQ) have been secondary. In some applications, thermal comfort and IAQ can be improved through adequate airflow and proper introduction of replacement air. In many of today's applications, outside air that meets IAQ standards is the most energy-efficient source for kitchen hood replacement air. ASHRAE *Standard* 62.1 requires that 5.1 L/s outside air per person, based on a maximum occupancy of 75 persons per 100 m^2, be brought into the dining area. For cafeterias and fast food dining, the outside air requirement is 4.7 L/s per person, based on 100 persons per 100 m. The requirement is 4.7 L/s per person in nonsmoking bars/cocktail lounges at 100 persons per 100 m^2. Kitchens require 6.6 L/s per person based on 22 persons per 100 m^2; however, kitchen requirements for outside air are superseded by the makeup air needs of the exhaust hoods. These requirements may be increased or decreased in certain areas if approved by the authority having jurisdiction. Outside air requirements sometimes affect HVAC system sizing and require another means of introducing outside air. A further requirement of *Standard* 62.1, that outside air be sufficient to provide for an exhaust rate of at least 3.5 L/s per square metre of kitchen space, is generally easily met.

Replacement Air Introduction

Replacement air may be introduced into the building through conventional HVAC apparatus, ventilators (no conditioning), or dedicated kitchen makeup air units and replacement air units. Replacement-air units are specifically designed to supply heated and/or cooled 100% outside air.

Conventional HVAC units used as replacement air sources may have fixed outside air intakes or economizer-controlled outside air dampers. HVAC units with economizers should have a barometric relief damper either in the return ductwork or in the HVAC unit itself. As the amount of outside air is increased, the increase in pressure in the system will open the relief damper, so that the return air volumetric rate is only enough to maintain approximately the amount of design supply air. The supply fan runs at a constant speed and thus moves a constant volume of air. The amount of air required for dedicated replacement air becomes the minimum set point for the economizer damper when the hoods are operating. Fixed outside air intakes must be set to allow the required amount of replacement air. Outside air dampers should be interlocked with hood controls to open to a preset minimum position when the hood system is energized. If the zone controls call for cooling, and outside conditions are within economizer range, the outside damper may be opened to allow greater amounts of outside air. The maximum setting for outside air dampers in unitary HVAC units is typically 25 to 30% of total unit air volume when compressors are running.

Operating in economizer mode should not change air discharge velocities or volumes, because the supply fan runs at a constant speed and thus moves a constant volume of air. However, field experience shows that large increases in air discharge velocities or volumes can occur at diffusers when HVAC units go into economizer mode. This is because the static loss through the fresh-air intake is considerably less than through the return air duct system, and thus a change from return air to fresh air reduces the overall static through the system, resulting in a relative increase in the total system flow. This can create air balance problems that negatively affect hood performance because of interference with capture and containment supply flow patterns at the hoods. A large increase in air velocity or volume from supply diffusers indicates a need for better balance between the fresh air and return air static losses. Some HVAC manufacturers state that a relief fan is required to ensure proper air balance if economizer controls call for outside air greater than 50% during economizer operation mode. A relief fan addresses static losses in the return duct system, thus helping minimize the static difference with the fresh-air intake. Lack of a barometric relief damper, or constrictions in the return ductwork, also may be the source of the problem.

In smaller commercial buildings, including restaurants and strip centers, individual unitary rooftop HVAC equipment is common. This unitary equipment may not be adequate to supply 100% of the replacement air volume. Outside air must be considered in the initial unit selection to obtain desired unit operation and space comfort. The space in which the hood is located should be maintained at a neutral or negative pressure relative to adjacent spaces. Therefore, HVAC economizers are not recommended for equipment supplying air directly to the space in which the hood is located, unless the economizer installation includes equipment and controls to maintain overall system air balance and to prevent excessive air discharge velocities or volumes.

Using enthalpy or temperature control is recommended. These controls cycle HVAC compressor(s), water supply, or heat source off when outside air conditions warrant and open outside air dampers if economizer controls are used. These additional controls provide kitchen comfort while conserving energy and saving money.

Replacement Air Categories

Three categories of replacement air have been defined for design of energy-efficient replacement air systems: supply, makeup, and transfer. IAQ engineers must design outside air systems to meet total building ventilation requirements. Replacement air for kitchen ventilation must integrate into the total building IAQ design. Total kitchen ventilation replacement air may consist of only dedicated makeup air; however, in many energy-efficient designs, outside air required for ventilating the kitchen or adjacent spaces is used as supply or transfer air to augment or even eliminate the need for dedicated makeup air. Typically, replacement air will be a combination of categories from multiple sources. The source of replacement air typically determines its category.

Supply air is outside air introduced through the HVAC or ventilating apparatus, dedicated to the comfort conditioning of the space in which the hood is located. In many cases this may be an ideal source of replacement air as it also provides comfort conditioning for the occupants.

Makeup air is outside air introduced through a system dedicated to provide replacement air specifically for the hood. It is typically delivered directly to or close to the hood. This air may or may not be conditioned. When conditioned, it may be heated only; generally only in extreme environments will it be cooled. When included, makeup air typically receives less conditioning than space supply air. The IMC (ICC 2006a) requires makeup air be conditioned to within 5.5 K of the kitchen space, except when introducing replacement air does not decrease kitchen comfort (see the section on Energy Considerations for additional information). This can be accomplished with proper distribution design. Typical sources of makeup air conditioning include electric resistance, direct and indirect gas-fired units, evaporative coolers, and water coils for cooling or heating (freeze protection required). Temperature of makeup air introduced varies with distribution system and type of operation.

Transfer air is outside air, introduced through the HVAC or ventilating apparatus, dedicated to comfort conditioning and ventilation requirements of a space adjacent to the hood. The device providing transfer air must be in operation and supplying outside air while the hood is operating. Air must not be transferred from spaces where airborne contaminants such as odors, germs, or dust may be introduced into the food preparation or serving areas. Air may be transferred through wall openings, door louvers, or ceiling grilles connected by duct above the ceiling. Depending on grille and duct pressure drop, a transfer fan(s) may be required to avoid drawing transfer air through lower-pressure-drop openings. When using openings through which food is passed, transfer velocities should not exceed 0.25 m/s to avoid excessive cooling of the food. Transfer air is an efficient source of replacement air because it performs many functions, including ventilating and/or conditioning the adjacent space, replacing air for the hood, and additional conditioning for the space in which the hood is located. Only the portion of air supplied to the adjacent space that originated as outside air may be transferred for replacement air. The IMC (ICC 2006a) recognizes the use of transfer air as a replacement (makeup) air source. In large

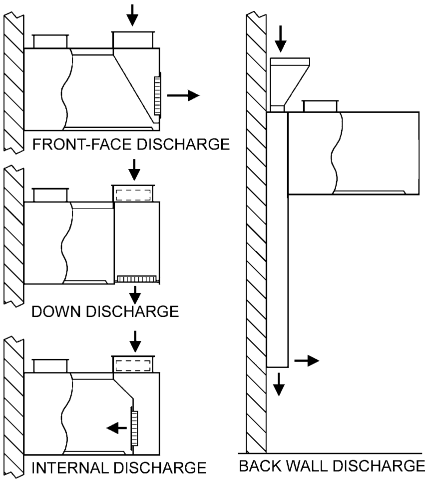


Fig. 23 Internal Methods of Introducing Replacement Air

buildings such as malls, supermarkets, and schools, adequate transfer air may be available to meet 100% of hood replacement air requirements. Malls and multiple-use-occupancy buildings may specify a minimum amount of transfer air to be taken from their space to keep cooking odors in the kitchen, or they may specify the maximum transfer air available to hold down the cost of conditioning outside air. Code restrictions may prevent the use of corridors as spaces through which transfer air may be routed. Conditions of transfer air are determined by conditioning requirements of the space into which the air is initially supplied.

Air Distribution

The design of a replacement air distribution system can enhance or degrade hood performance. Systems that use a combination of supply, makeup, and transfer air include various components of distribution. Distribution from each source into the vicinity of the hood, must be designed to eliminate high velocities, eddies, swirls, or stray currents that can interrupt the natural rising of the thermal plume from cooking equipment into the hood, thus degrading the performance of the hood. Methods of distribution may include conventional diffusers, compensating hood designs, transfer devices, and simple openings in partitions separating building spaces. Regardless of the method selected, it is important to always deliver replacement air to the hood (1) at proper velocity and (2) uniformly from all directions to which the hood is open. This minimizes excessive cross-currents that could cause spillage. Proper location and/or control of HVAC return grilles is therefore critical. The higher air velocities typically recommended for general ventilation or spot cooling with unconditioned air (0.4 to 1.0 m/s at worker) should be avoided around the hood. Hood manufacturers offer a variety of compensating hoods, plenums, and diffusers designed to introduce replacement air effectively.

Compensating Hoods. A common way of distributing replacement air is through compensating systems that are integral with the hood. Figure 23 shows four typical compensating hood configurations. Because actual flows and percentages may vary with hood design, the manufacturer should be consulted about specific applications. The following are typical descriptions.

A recent makeup air study (Brohard et al. 2003) investigated the effects of six strategies on three hood types, and found that each makeup air strategy and specific configuration tested compromised the exhaust hood's ability to completely capture and contain the thermal plume and/or effluents at higher makeup airflow rates (expressed as a percentage of the threshold exhaust rate). Temperature of locally supplied makeup air also affected hood performance, because air density affects the dynamics of air movement around the hood. Generally, hotter makeup air temperatures (e.g., greater than 32°C) affect hood performance more adversely than cooler air (e.g., less than 24°C).

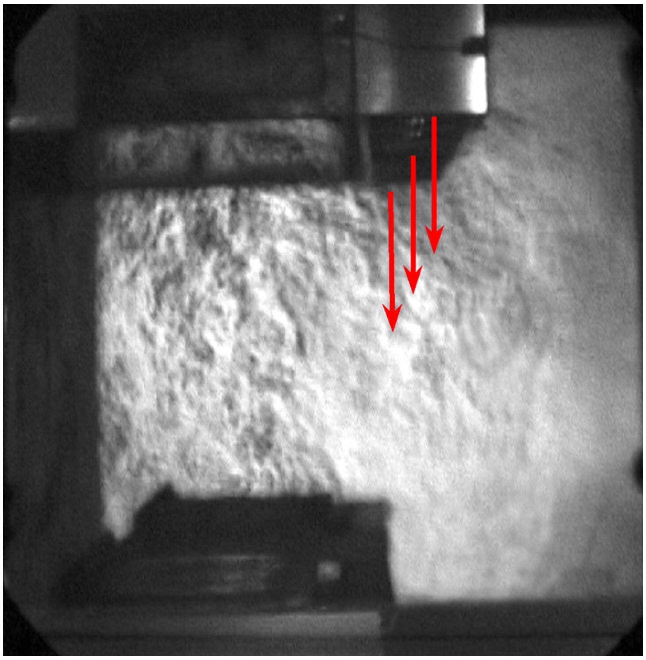


Fig. 24 Schlieren Image Showing Thermal Plume Being Pulled Outside Hood by Air Curtain
(Brohard et al. 2003)

Air Curtain Supply. This method is typically used for spot-cooling the cooking staff to counter the severe radiant heat generated from equipment such as charbroilers. The air must be heated and/or cooled, depending on local climate. Air curtain discharge can be along the length of the hood front only or along all open sides of the hood. When discharge velocity is too low, air tends to enter the hood directly and may have little effect on hood performance. When discharge velocity is too high, air entrains the cooking plume and spills it into the room. Ideal velocity and throw can improve hood performance and redirect the thermal plume toward the filters. Discharge velocities must be carefully selected to avoid discomfort to personnel and cooling of food.

Limit the percentage of makeup air supplied through an air curtain to less than 20% of the hood's exhaust flow. At these low air velocities, an air curtain may enhance capture and containment, depending on design details. However, at higher makeup airflow rates, the air curtain is one of the worst performing makeup air strategies. The negative effect of an air curtain is clearly illustrated in Figure 24 by the schlieren flow visualization recorded during a test of a wall-mounted canopy hood operating over two underfired broilers.

Introducing makeup air through an air curtain is a risky option. An air curtain (by itself or in combination with another pathway) is not recommended, unless velocities are minimized and the designer has access to performance data on the actual air curtain configuration being specified. Typical air curtains are easily adjusted, which could cause cooking effluent to spill into the kitchen by inadvertently creating higher-than-specified discharge velocities.

Back-Wall Supply. A makeup air plenum is installed between the back of the hood and wall. The full-length plenum typically extends down the wall to approximately 150 mm below the cooking surface or 600 to 900 mm above the floor. The depth of the plenum is typically 150 mm. Makeup air is discharged behind and below the cooking equipment. The bottom of the plenum is provided with diffusers and may also include a balancing damper. As with front-face dis-

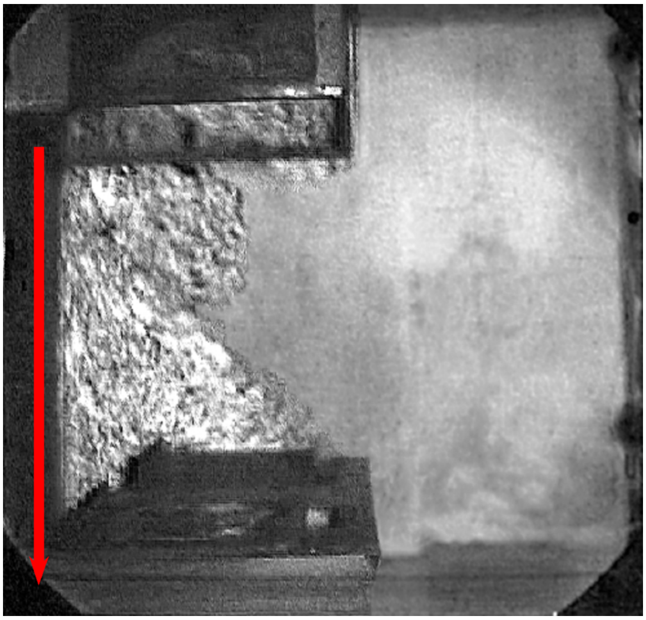


Fig. 25 Schlieren Image Showing Thermal Plume Being Captured with Back-Wall Supply
(Brohard et al. 2003)

charge, air volume and discharge velocity dictate how far into the space the replacement air will travel. The amount of travel and local climate dictate the amount of heating and/or cooling needed. Support for wall shelves, salamander broilers, or cheesemelters mounted under the hood must be considered. The plenum structure typically does not provide sufficient support for mounting these items.

Back-wall supply can be an effective strategy for introducing makeup air (Figure 25). In most cases, it allows significant amounts of air to be locally supplied without a detrimental effect on hood C&C performance. Local makeup air mostly enters the kitchen space, rather than remaining contained in the cooking zone. This potentially creates an additional heat and moisture load on the kitchen, particularly because most makeup air supplied is mixed with room air before being exhausted.

To help ensure proper performance, the discharge of the back-wall supply should be at least 300 mm below cooking surfaces of appliances, to prevent the relatively high-velocity makeup air from interfering with gas burners and pilot lights. Back-wall plenums with larger discharge areas may provide increased airflow rates as long as discharge velocities remain below maximum thresholds. The quantity of air introduced through the back-wall supply should be no more than 60% of the hood's exhaust flow.

Front-Face Supply. Supplying air through the front face of the hood is a configuration recommended by many hood manufacturers. In theory, air exits the front-face unit horizontally into the kitchen space. However, a front-face discharge with louvers or perforated face can perform poorly, if its design does not consider discharge air velocity and direction. Figure 26 presents a poorly designed perforated face supply, which can negatively affect hood capture performance in the same way as an air-curtain or four-way diffuser. To improve front-face performance, internal baffling and/or a double layer of perforated plates may be used improve the uniformity of airflow. In addition, greater distance between the lower capture edge of the hood and the bottom of the face discharge area may decrease the tendency of the makeup air supply to interfere with hood capture and containment. In general, face discharge velocities should not exceed 0.75 m/s (i.e., makeup air flow rate divided by gross discharge area) and should exit the front face in a horizontal direction.

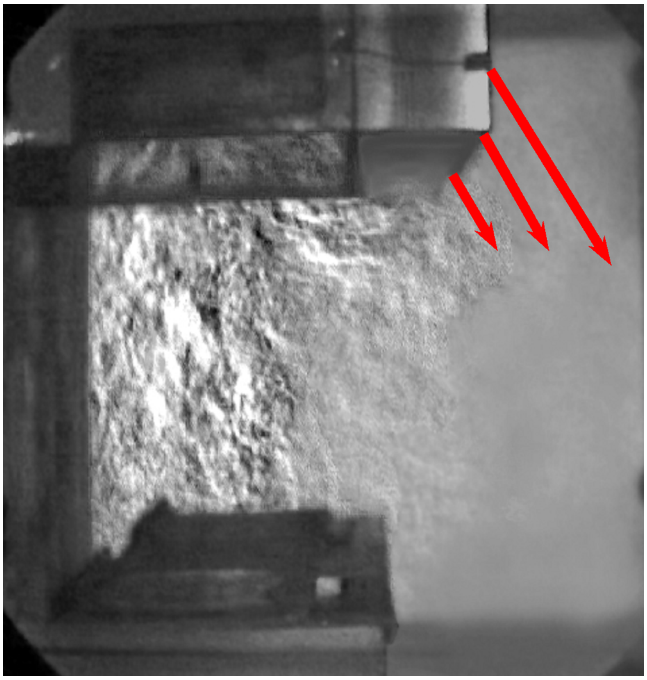


Fig. 26 Schlieren Image Showing Thermal Plume Being Pulled Outside Hood by Front Face
(Brohard et al. 2003)

Internal Makeup Air. Commonly known as **short-circuit**, this method introduces replacement air directly into the exhaust hood cavity. This design has limited application, and the amount of air that can be introduced varies considerably with the type of cooking equipment and exhaust flow rate. As noted previously, thermal currents from cooking equipment create a plume of a certain volume that the hood must remove. The hood must therefore draw at least this volume of air from the kitchen, in addition to any internal makeup. If the net exhaust flow rate (total exhaust less internal replacement air) is less than the plume volume, part of the plume may spill out of the hood. Internal replacement air is typically not conditioned; however, depending on local climate, manufacturer's design, type of cooking equipment, and local codes, conditioning may be required. Some local authorities approve internal discharge hoods, and some do not. For unlisted hoods, IMC (2006a) requires the net quantity of exhaust air to be calculated by subtracting any airflow supplied directly to a hood cavity from the total exhaust flow rate of a hood. Listed hoods are operated in accordance with the terms of the listing. All applicable codes must be consulted to ensure proper criteria are followed.

When short-circuit hoods are operated with excessive internal makeup air, they typically fail to capture and contain the cooking effluent (Figure 27). Additionally, the introduction of untempered makeup air results in uncomfortable kitchen conditions. Independent research recommends not using this compensating hood design; therefore, there is no additional design information in this chapter.

Multiple Discharge. This method may combine internal, perimeter, air curtain, and/or front face. Each may be served by a separate or common plenum. Balancing dampers may be provided for one or both discharge arrangements. These dampers may be used to fine-tune the amount of air discharged through the air curtain or front face. However, this method inherits the installation and maintenance problems of each of the individual types, and the combining of them tends to compound the associated problems with their design, installation and maintenance.

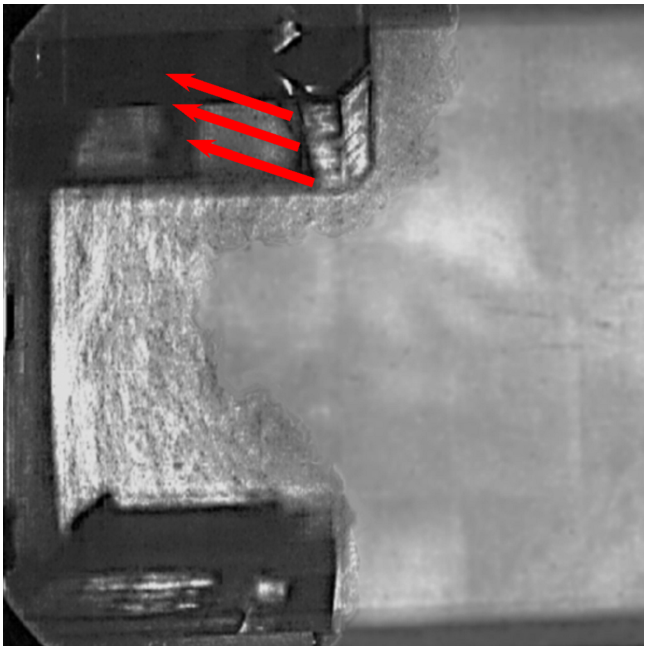


Fig. 27 Schlieren Image Showing Thermal Plume Being Displaced by Short-Circuit Supply, Causing Hood to Spill
(Brohard et al. 2003)

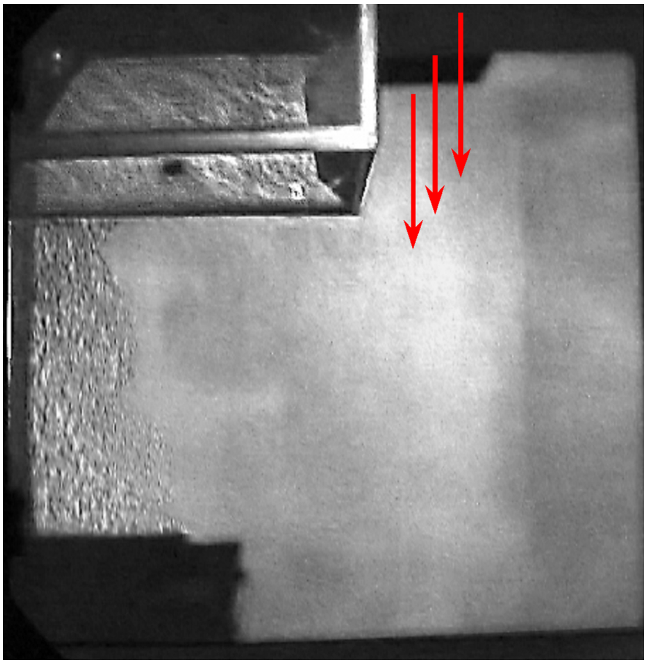


Fig. 28 Schlieren Image Shows Effective Plume Capture with Makeup Air Supplied Through 400 mm Wide Perforated Perimeter Supply
(Brohard et al. 2003)

Perforated Perimeter Supply. Perforated perimeter supply is similar to a front-face supply, but the air is directed downward, as in Figure 28, toward the hood capture area. This may be advantageous under some conditions, because air is directed downward into the hood capture zone.

For proper hood performance, discharge velocities should not exceed 0.75 m/s (i.e., makeup air flow rate divided by gross discharge area) from any section of the diffuser, and the distance to lower edge of the hood should be no less than 460 mm, or the system begins to act like an air curtain. An increase in the plenum discharge area lowers the velocity for a given flow of makeup air and reduces the chance of it affecting capture and containment. If the perforated perimeter supply is extended along the sides of the hood as well as the front, the increased area allows proportionally more makeup air to be supplied.

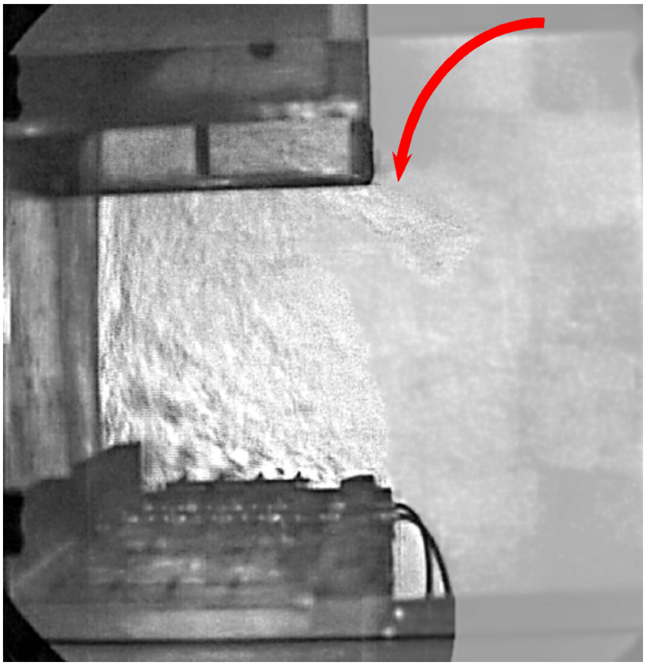


Fig. 29 Schlieren Image Showing Thermal Plume Being Pulled Outside Hood by Air Discharged From Four-Way Diffuser
(Brohard et al. 2003)

Traditional Registers. There are various ways to distribute replacement air in the vicinity of the hood to avoid cross-currents that degrade hood performance. Nonaspirating diffusers are recommended, especially adjacent to the hood. Typical devices include the following (for more information on diffusers, see Chapter 33 of the 2005 *ASHRAE Handbook—Fundamentals* and Chapter 17 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*).

Louvered Ceiling Diffusers. Air from these aspirating, two-, three-, or four-way diffusers should not be directed toward exhaust hoods, where it might disturb the thermal plume and adversely affect hood performance. The diffuser should be located so that the jet velocity at the lip of the hood does not exceed 0.4 m/s.

Four-Way Ceiling Diffusers. Four-way diffusers located close to kitchen exhaust hoods (Figure 29) can have a detrimental effect on hood performance, particularly when flow through the diffuser approaches its design limit.

Perforated-plate ceiling diffusers can be used near the hood, and a greater number of ceiling diffusers reduce air velocities for a given supply rate. To help ensure proper hood performance, air from a diffuser near the hood should not be directed toward the hood. They are not recommended within 4.5 m of the hood. If ceiling-supplied air must be directed toward a hood, air discharge velocity at the diffuser face should be set at a design value so that the terminal velocity does not exceed 0.4 m/s at the edge of the hood capture area.

Perforated Diffusers. These nonaspirating, perforated-face diffusers may have internal deflecting louvers, but should not be capable of directing the airflow toward the hood. The diffuser should be located so that the jet velocity at the lip of the hood does not exceed

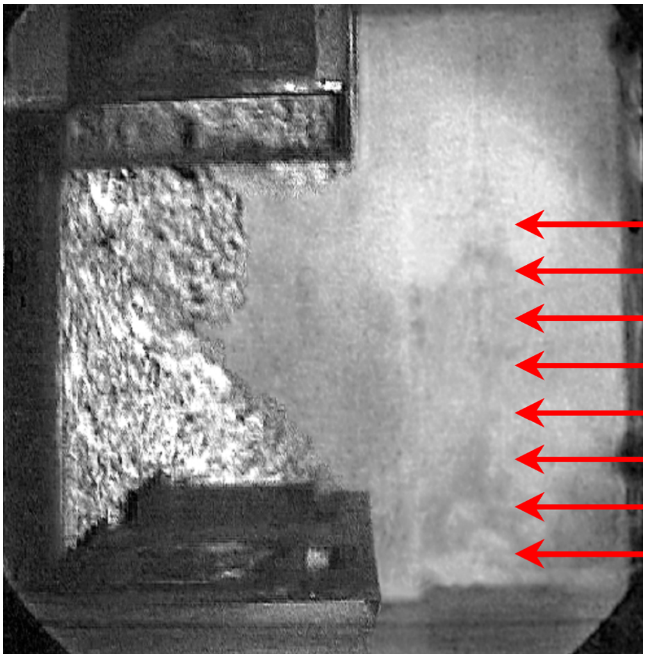


Fig. 30 Schlieren Image Showing Plume Being Effectively Captured when Makeup Air Is Supplied at Low Velocity From Displacement Diffusers
(Brohard et al. 2003)

0.4 m/s. In some code jurisdictions, when conventional ceiling diffusers are used, only perforated diffusers are allowed in commercial kitchens.

Slot Diffusers. Because the slot opening of these devices is generally small compared to air volume, air velocity is often higher than that which would be obtained with two-, three-, and four-way diffusers. Also, because airflow is mostly downward, the potential for negatively affecting hood performance is quite high if outlets are near the hood. If used with relatively high ceilings, the potential for negative impact is less because the velocity diminishes as air diffuses downward. Slot diffusers are usually nonaspirating.

Displacement Diffusers. These devices, designed to provide low-velocity laminar flow over the diffuser surface, typically supply air from 10 to 21°C in a kitchen, depending on equipment loads. Hotter, stratified air is removed from the ceiling through exhaust ducts or returned to the HVAC system to be conditioned. In contrast with ceiling diffusers, which require complete mixing to be effective, stratification is the desired effect with displacement diffusers.

Displacement ventilation was the baseline for Brohard et al.'s (2003) makeup air study, because it provided a uniform, nearly laminar bulk airflow. This low-velocity bulk airflow is optimal for attaining C&C with the lowest exhaust rate. Therefore, supplying makeup air through displacement diffusers (Figure 30) is an effective strategy for introducing replacement air. Unfortunately, displacement diffusers require floor or wall space, which is usually at a premium in the commercial kitchen. A possible solution may be remote displacement diffusers (built into a corner) to help distribute makeup air into the kitchen when transfer air is not available.

Other Factors That Influence Hood Performance.

Hood Style. Wall-mounted canopy hoods function effectively with a lower exhaust flow rate than single-island hoods. Island canopy hoods are more sensitive to makeup air supply and cross drafts than wall-mounted canopy hoods. Back-shelf/proximity hoods generally exhibit lower capture and containment exhaust rates, and in some cases, perform the same job at one-third of the exhaust rate required by a wall-mounted canopy hood.

Cross Drafts. Cross drafts have a detrimental effect on all hood/appliance combinations. Cross drafts adversely affect island canopy hoods more than wall-mounted canopy hoods. A fan in a kitchen, especially pointing at the cooking area, severely degrades hood performance and may make capture impossible. Cross drafts required at least a 37% increase in exhaust flow rate; in some cases, C&C could not be achieved with a 235% increase in exhaust rate. Cross drafts can result from portable fans, movement in the kitchen, or an unbalanced HVAC system, which may pull air from open drive-through windows or doors.

Side Panels. Side (or end) panels allow a reduced exhaust rate in most cases, because they direct replacement airflow to the front of the hood. Installing side panels improved C&C performance for static conditions an average 10 to 15% and up to 35% for dynamic (cross-draft) conditions. They are a relatively inexpensive way to enhance performance and reduce the total exhaust rate. Partial side panels can provide virtually the same benefit as full panels. One of the greatest benefits of side panels is to mitigate the negative effect of cross drafts.

The primary recommendation from the study was to reduce the impact that locally supplied makeup air may have on hood performance by minimizing makeup air velocity as it is introduced near the hood. This can be accomplished by minimizing the volume of makeup air through any single distribution system, maximizing the area of the diffusers through which the makeup air is supplied, or distributing through multiple pathways. Makeup air supplied through displacement ventilation diffusers, perforated diffusers located in the ceiling as far as possible from the hood, or as transfer air from the dining room generally works well if air velocities approaching the hood are less than 0.4 m/s. However, makeup air introduced close to an exhaust hood might interfere with the hood's ability to capture and contain. The chances of makeup air affecting hood performance increase as the percentage of the locally supplied makeup air (relative to the total exhaust) is increased. In fact, the 80% rule of thumb for sizing airflow through a makeup air system may be a recipe for trouble.

Design Recommendations. The first step to reducing the makeup air requirement is lowering the design exhaust rate, which can be accomplished by prudent selection and application of UL *Standard* 710 listed hoods. Using side panels on canopy hoods to increase effectiveness, mitigate cross drafts, and reduce heat gain is highly recommended. The next step is to take credit for outside air that must be supplied by the HVAC system to meet code requirements for ventilating the dining room. Depending on the architectural layout, it may be practical to transfer most of this air to the kitchen, improving hood performance and the kitchen environment by introducing conditioned dining room air.

SYSTEM INTEGRATION AND BALANCING

System integration and balancing bring the many ventilation components together to provide the most comfortable, efficient, and economical performance of each component and of the entire system. In commercial kitchen ventilation, the supply air system (typically referred to as the HVAC system) must integrate and balance with the exhaust system. Optimal performance is achieved more by effective use of components through controls and airflow adjustments than by selection or design of the system and components. The following fundamentals for restaurants, and kitchens in particular, should be considered and applied within the constraints of the particular location and its equipment and systems.

Principles

Although there are exceptions, the following are the fundamental principles of integrating and balancing restaurant systems for both comfort control and economical operation:

- In a freestanding restaurant, the overall building should always be slightly positively pressurized compared to the outside to minimize infiltration of untempered air, as well as dirt, dust, and insects, when doors are opened. In multiple-occupancy buildings, a slight negative pressure in the restaurant is desirable to minimize odor migration from the restaurant to other occupancies.
- Every kitchen should always be slightly negative compared to the rooms or areas immediately surrounding it, to (1) better contain unavoidable grease vapors in the kitchen area and limit the extent of cleanup necessary, (2) keep cooking odors in the kitchen area, and (3) prevent the generally hotter and more humid kitchen air from diminishing the comfort level of adjacent spaces, especially dining areas.
- Cross-zoning of airflow should be minimal, especially in temperate seasons, when adjacent zones may be in different modes (e.g., economizer versus air conditioning or heating). Three situations to consider are the following:
  - In transitions from winter to spring and from summer to fall, the kitchen zone could be in economizer, or even mechanical cooling mode, while dining areas are in heating mode. Bringing heated dining-area supply air into a kitchen that is in cooling mode only adds to the cooling load. In some areas, this situation is present every day.
  - When all zones are in the same mode, it is more acceptable, and even more economical, to bring dining-area air into the kitchen. However, the controls to automatically effect this method of operation are more complex and costly.
  - If dedicated kitchen makeup air is heated, thermostatic control of the heating source should ideally be based on kitchen temperature rather than outside temperature. Otherwise, with usual kitchen heat gains and subsequent low balance points for heating and cooling, it is possible that makeup air heating and kitchen mechanical cooling might be operated simultaneously.
- Typically, no drafts should be noticeable, and temperatures should vary no more than 0.6 K in dining areas and 1.7 K in kitchen areas. These conditions can be achieved with even distribution and thorough circulation of air in each zone by an adequate number of registers sized to preclude high air velocities. If there are noticeable drafts or temperature differences, customers and restaurant personnel will be distracted and will not enjoy dining or working.

Both design concepts and operating principles for proper integration and balance are involved in achieving desired results under varying conditions. The same principles are important in almost every aspect of restaurant ventilation.

In designing restaurant ventilation, all exhaust is assumed to be in operation at one time, and the design replacement air quantity is a maximum requirement because the heating and cooling equipment are sized for maximum design conditions.

In restaurants with a single large exhaust hood, balancing should be set for this one operation only. In restaurants with multiple exhaust hoods, some may be operated only during heavy business hours or for special menu items. In this case, replacement air must be controlled to maintain minimum building positive pressure and to maintain the kitchen at a negative pressure under all operating conditions. The more variable the exhaust, or the more numerous and smaller the zones involved, the more complex the design, but the overall pressure relationship principles must be maintained to provide optimum comfort, efficiency, and economy.

A different application is a kitchen with one side exposed to a larger building with common or remote dining. Examples are a food court in a mall or a small restaurant in a hospital, airport, or similar building. Positive pressure at the front of the kitchen might cause some cooking grease, vapor, and odors to spread into the common building space, which would be undesirable. In such a case, the kitchen area is held at a negative pressure relative to other common building areas as well as to its own back room storage or office space.

Air Balancing

Balancing is best performed when the manufacturers of all the HVAC equipment can provide a certified reference method of measuring the airflows, rather than depending on generic measurements of duct flows or other forms of measurement in the field, which can be in error by 20% or more. The equipment manufacturer should be able to develop a reference method of measuring airflow in a portion of the equipment that is dynamically stable in the laboratory as well as in the field. This method should relate directly to airflow by graph or formula.

The general steps for air balancing in restaurants are as follows:

1. Exhaust hoods should be set to their proper flow rates, with supply and exhaust fans on.
2. Next, supply airflow rate, whether part of combined HVAC units or separate replacement air units, should be set to design values through the coils and the design supply flows from each outlet, with approximately correct settings on the outside airflow rate. Then, correct outside and return airflow rates should be set proportionately for each unit, as applicable. These settings should be made with exhaust on, to ensure adequate relief for the outside air.

   Where outside air and return air flows of a particular unit are expected to modulate, there should ideally be similar static losses through both airflow paths to preclude large changes in total supply air from the unit. Such changes, if large enough, could affect the efficiency of heat exchange and could also change airflows within and between zones, thereby upsetting air distribution and balance.
3. Next, outside air should be set with all fans (exhaust and supply) operating. Pressure difference between inside and outside should be checked to see that (1) nonkitchen zones of the building are at a positive pressure compared to outside and (2) kitchen zone pressure is negative compared to the surrounding zones and negative or neutral compared to outside.

   For applications with modulating exhaust, every step of exhaust and replacement should be shut off, one step at a time. Each combination of operation should be rechecked to ensure that design pressures and flows are maintained in each zone and between zones. This requires that the replacement airflow rate compensate automatically with each increment of exhaust. It may require some adjustments in controls or in damper linkage settings to get the correct proportional response.
4. When the preceding steps are complete, the system is properly integrated and balanced. At this time, all fan speeds and damper settings (at all modes of operation) should be permanently marked on the equipment and in the test and balance report. Air balance records of exhaust, supply, return, fresh air, and individual register airflows must also be completed. These records should be kept by the food service facility for future reference.
5. For new facilities, after two or three days in operation (no longer than a week and usually before the facility opens), all belts in the system should be checked and readjusted because new belts wear in quickly and could begin slipping.
6. Once the facility is operational, the performance of the ventilation system should be checked to verify that the design is adequate for actual operation, particularly at maximum cooking and at outside environmental extremes. Any necessary changes should be made, and all the records should be updated to show the changes.

Rechecking the air balance should not be necessary more than once every two years unless basic changes are made in facility operation. If there are any changes, such as adding a new type of cooking equipment or deleting exhaust connections, the system should be modified accordingly.

Multiple-Hood Systems

Kitchen exhaust systems serving more than a single hood present several design challenges not encountered with single-hood systems. One of the main challenges of multiple-hood exhaust systems is air balancing. Because balancing dampers are not permitted in the exhaust ducts, the system must be balanced by design. Zoning may be desirable for a balanced design and to improve energy conservation. Hood accessories are now available to allow balancing at individual hoods. Additionally, most filters come in varying sizes to allow pressure loss equalization at varying airflows. Some hoods and grease filters have adjustable baffles that allow airflow to be adjusted at the hood. These may be helpful for relatively fine balancing, but the system must provide most of the balancing. System zoning is preferred, because incorrect installation of a multibranch system can lead to complex problems. Adjustable filters should not be used when they can be interchanged between hoods or within the same hood, because an interchange could disrupt the previously achieved balance. Balancing can also be accomplished by changing the number and/or size of filters.

For correct flow through a branch duct in a multiple-hood system, the static pressure loss of the branch must match the static pressure loss of the common duct upstream from the point of connection. Any exhaust points subsequently added or removed must be designed to comply with the minimum velocities required by code and to maintain the balance of the remaining system. In cases such as master kitchen-exhaust systems, which are sometimes used in shopping center food courts, no single group is responsible for the entire design. The base building designer typically lays out ductwork to (or through) each tenant space, and each tenant selects a hood and lays out connecting ductwork. Often the base building designer has incomplete information on tenant exhaust requirements. Therefore, one engineer must be responsible for defining criteria for each tenant's design and for evaluating proposed tenant work to ensure that tenant designs match the system's capacity. The engineer should also evaluate any proposed changes to the system, such as changing tenancy. Rudimentary computer modeling of the exhaust system may be helpful (Elovitz 1992). Given the unpredictability and volatility of tenant requirements, it may not be possible to balance the entire system perfectly. However, without adequate supervision, it is very probable that at least part of the system will be badly out of balance.

For greatest success with multiple-hood exhaust systems, minimize pressure losses in the ducts by keeping velocities low, minimizing sharp transitions, and using hoods with relatively high pressure drops. When pressure loss in the ducts is low compared to the loss through the hood, changes in pressure loss in the ductwork because of field conditions or changes in design airflow will have a smaller effect on total pressure loss and thus on actual airflow.

Minimum code-required air velocity must be maintained in all parts of the exhaust ductwork at all times. If fewer or smaller hoods are installed than the design anticipated, resulting in low velocity in portions of the ductwork, the velocity must be brought up to the minimum. One way is to introduce replacement air, preferably untempered, directly into the exhaust duct where it is required (Figure 31). The bypass duct should connect to the top or sides (at least 50 mm from the bottom) of the exhaust duct to prevent backflow of water or grease through the bypass duct when fans are off. This arrangement is shown in NFPA *Standard* 96 and should be discussed with the authority having jurisdiction.

A fire damper should be provided in the bypass duct, located close to the exhaust duct. Bypass duct construction should be the same as the exhaust duct construction, including enclosure and clearance requirements, for at least a metre beyond the fire damper. Means to adjust the bypass airflow must be provided upstream of the fire damper. All dampers must be in the clean bypass air duct so they are not exposed to grease-laden exhaust air. The difference in pressure between replacement and exhaust air duct may be great; the balancing device must be able to make a fine airflow adjustment against this pressure difference. It is best to provide two balancing devices in series, such as an orifice plate or blast gate for coarse adjustment followed by an opposed-blade damper for fine adjustment.

Directly measuring air velocities in the exhaust ductwork to assess exhaust system performance may be desirable. Velocity (pitot-tube) traverses may be performed in kitchen exhaust systems, but holes drilled for the pitot tube must be liquidtight to maintain the fire-safe integrity of the ductwork per NFPA *Standard* 96. Holes should never be drilled in the bottom of a duct, where they may collect grease. Velocity traverses should not be performed when cooking is in progress because grease collects on the instrumentation.

Dynamic Volumetric Flow Rate Effects

Design exhaust flow rates for kitchen hoods are determined either by laboratory tests or by building code requirements. In both cases, the intent is to ensure capture and containment under maximum cooking load conditions. The majority of kitchen exhaust systems use fixed-speed fans. Because a fan is a constant-volumetric mover, at any given speed it always moves the same volume of air, regardless of the density of the air, because of temperature, humidity, flue products of combustion, and grease vapor. Thus, for a given motor speed, a kitchen exhaust fan will always move the same volume of air whether during maximum cooking, minimum cooking, with hot appliances at idle, or even with cold appliances. Although the air volume removed by the exhaust fan is constant, the amount of air removed from the kitchen space varies according to cooking appliance operating conditions:

- During full-load cooking, the exhaust system pulls the least amount of air from the kitchen, and requires the least amount of replacement air to keep a balanced system. Air entering the fan inlet consists of the air expanded by the hot cooking surface, effluent generated by the cooked food, entrained kitchen air to ensure capture and containment at the perimeter of the hood, and flue gases when gas-fired equipment is used. This is usually the lightest-density, highest-temperature air removed by the fan.
- During ready-to-cook (idle) conditions (appliances at operating temperature, but no cooking effluent being produced), air being exhausted is a combination of kitchen air (expanded by the hot cooking surface) and entrained kitchen air. Compared to most full-load cooking conditions, the required replacement air volume from the kitchen increases to fulfill the exhaust fan requirement and to keep a balanced system. Air entering the fan inlet is denser than under cooking conditions because the increased volume of kitchen air has a lower temperature than cooking effluent does.
- During cold conditions, air entering the fan inlet is at or near kitchen temperature and humidity conditions. This is the condi-

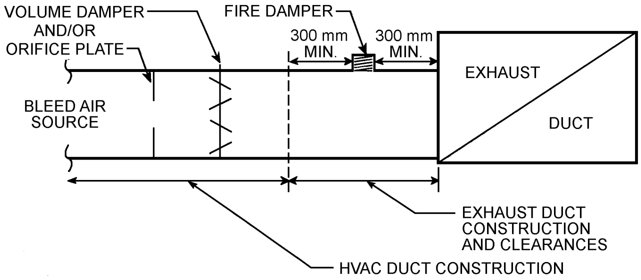


Fig. 31 Method of Introducing Replacement Air Directly into Exhaust Duct

tion with the greatest amount of air leaving the kitchen and requires the greatest amount of replacement air to keep a balanced system. This is the heaviest-density air of the three appliance operating conditions. In a kitchen, this condition usually occurs for a short while when the exhaust system is first started and before the cooking appliances are heated; it can also occur when the exhaust system is operated to check equipment performance, to assess the air balance and distribution, or to just provide ventilation during a cleaning or renovation project.

Changes in the amount of air volume removed from the kitchen based on appliance operations have implications for (1) setting hood exhaust fan speed in the field, (2) determining the amount of replacement air or transfer air for the kitchen, and (3) air-conditioning and heating loads attributed to makeup air or transfer air.

Appliance temperatures, food and flue products, and exhaust flow rates determine the volume created by the cooking process. The resulting air temperatures vary widely because of overexhausting, close-coupling, hood style, etc. Duct temperatures range from slightly above ambient for large, overexhausted systems to over 90°C for close-coupled minimum-flow systems. The result is a difference in exhaust and replacement air requirements. For instance, two griddles under a backshelf hood could show a 25 L/s difference between exhaust and replacement air, a two-deck oven could show a 95 L/s difference, and two chain charbroilers could show a 240 L/s difference.

The best practice for determining building air balance is to use hot/no cooking (idle) condition flow rates. Most restaurants spend about 70% of their time in this condition. If air balance is determined under cold conditions, the makeup or transfer air will be greater than required during hot/ready-to-cook and cooking operations. The result is a slightly higher pressure than required in the kitchen and may result in air transfer to other parts of the building.

Similarly, the best practice for determining heating and air-conditioning loads from makeup or transfer air is to use hot/no cooking condition flow rates. Using cold/no-cooking conditions will result in a larger design load estimate than required.

ENERGY CONSIDERATIONS

Energy conservation in restaurants depends on the following variables:

Climate. Outside temperature and humidity are key determinants of restaurant HVAC energy use. Because climatic zones vary dramatically in temperature and humidity, kitchen ventilation conservation designs have widely varying economic recovery periods. In new facilities, the designer can select conservation measures suitable for the climatic zone and the HVAC system to maximize the economic benefits.

Restaurant Type. Claar et al. (1985) defined five restaurant types: fast-food, full-service, coffee shop, pizza, and cafeteria. Restaurant associations identify many additional restaurant types, among which energy use varies significantly. As a result, some energy conservation measures work in all restaurants, whereas others may work only in specific types. For simplicity, this discussion classifies restaurants as cafeteria, fast-food, full-menu, and pizza.

Hood Type and Equipment Characteristics. The type of exhaust hood selected depends on such factors as restaurant type, restaurant menu, and food service equipment. Exhaust flow rates are largely determined by the food service equipment and hood style. The effectiveness of conservation measures, whether in a new design or as a retrofit, is also affected by the type of hood and food service equipment.

Energy Conservation Measures

Energy costs in restaurants vary from 2 to 6% of gross sales. The following major energy conservation measures can reduce commercial kitchen ventilation costs.

Custom-Designed Hoods. A typical cooking lineup combines food service equipment with different thermal updraft characteristics and exhaust flow rates depending on cooking load, cooking temperature, product cooked, fuel source, and so forth. Exhaust hoods are sized to handle the worst-case cooking appliance; during idle or off-peak periods, exhaust quantities may be excessive.

Custom-designed hoods for each piece of equipment can reduce exhaust/replacement air quantities and consequently reduce fan sizes, energy use, and energy costs for all types of restaurants. Hood manufacturers recommend exhaust flow rates based on either thermal current charts or empirical tests. To operate at flow rates lower than required by code, custom-designed hoods must be either listed or approved by the local code official.

Dining-Room Air for Kitchen Ventilation. Most fast-food and pizza restaurants do not physically segregate the kitchen from the dining room, so conditioned air moves from the dining area to the kitchen. Dining-room air cools the kitchen and provides replacement air for the kitchen exhaust.

Sometimes full-menu and cafeteria facilities are designed so that minimal replacement air transfers between the dining room and the kitchen; therefore, the majority of the replacement air must be made up by a kitchen makeup air unit.

In restaurants where the kitchen and dining room are physically segregated, ducts between the two areas allow conditioned replacement air to flow to the kitchen. This design can reduce kitchen replacement air requirements and enhance employee comfort, especially if the kitchen is not air conditioned. Of course, the dining room must have replacement air to replace the air transferred to the kitchen. Also, care must be taken to ensure that enough replacement air is introduced into the kitchen to meet the requirements of applicable codes and standards.

Heat Recovery from Exhaust Hood Ventilation Air. High-temperature effluent, often in excess of 200°C, heats replacement air to 35 to 95°C as it travels over the cooking surfaces and areas. It is frequently assumed that this heated exhaust air is suitable for heat recovery; however, smoke and grease in the exhaust air, with time, cover any heat transfer surface. Under these conditions, the heat exchangers require constant maintenance (e.g., automatic wash-down) to maintain acceptable heat recovery.

Because heat recovery systems are very expensive, only food service facilities with large amounts of cooking equipment and large cooking loads are good candidates for this equipment. Heat recovery may work in full-menu and cafeteria restaurants and in institutional food service facilities such as prisons and colleges. An exhaust hood equipped with heat recovery is more likely to be cost-effective where the climate is extreme. A mild climate, such as in California, is not conducive to use of this conservation measure. The principal obstacle to heat recovery from kitchen exhaust systems is that heat removal from the exhaust aids condensation of grease vapors on recovery system surfaces in the exhaust stream, resulting in lower heat transfer efficiency and higher maintenance requirements. An additional obstacle is providing enough heat transfer surface area cost-effectively.

Extended Economizer Operation. In most restaurants, mechanical cooling is required to keep the staff and customers cool. By operating in economizer mode, similar cooling can be achieved at less cost because only fans are operated and not compressors. Economizers can be used in lieu of or with mechanical cooling when the outside dry-bulb temperature (and sometimes humidity) is ±5.6 K lower than the return air condition. Economizer systems may be designed to increase ventilation by 25% or more over normal ventilation, or about 50 to 60% of system supply capacity. For additional savings, economizers can increase outside air to 100%, usually with fan-powered relief. See the on section Replacement Air Sources for design considerations for kitchen applications.

Analysis of energy-use data from monitoring food service facilities indicates that heating/cooling balance points for commercial kitchens may be significantly lower than the typical 18°C of other commercial buildings. One project that monitored seven diverse restaurants for an extended period (Claar et al. 1985) revealed an average balance point for the group of 11.8°C. Accordingly, though the temperature band for economizer operations in common commercial buildings might be limited to 16 to 24°C, kitchens may benefit from an economizer range starting in the lower teens, providing for much greater economic application and financial acceptance.

Optimized Heating and Cooling Set Points. IMC (ICC 2006a) requires that makeup air be conditioned to within 5.6 K of the kitchen space, except when the makeup air is part of the air-conditioning system and does not adversely affect comfort conditions in the occupied space. The exception is important because it allows the design to be optimized to take advantage of the typically lower heating/cooling balance points of commercial kitchens. Accordingly, it is essential that the heating set point of dedicated makeup units not be set higher than the forecasted heating/cooling balance point to avoid simultaneous operation of makeup heating and HVAC cooling. Designers should set the makeup unit heating exit temperature lower than the lowest temperature at which cooling will be activated.

Reduced Exhaust and Replacement (Makeup) Airflow Rates. Tempering outside replacement air can account for a large part of a food service facility’s heating and cooling costs. By reducing exhaust flow rates (and the corresponding replacement air quantity) when no product is being cooked, energy cost can be significantly reduced. Field evaluations by one large restaurant chain suggest that cooking appliances may be at zero load for 75% or more of an average business day (Spata and Turgeon 1995). When no smoke or grease-laden vapors are being produced, NFPA *Standard* 96 allows reduction of exhaust quantities. The only restriction on the reduced exhaust quantity is that it be “sufficient to capture and remove flue gases and residual vapors.”

Historically, however, it has been difficult to reduce exhaust flow rates in a retrofit because of the minimum duct velocity restriction. ASHRAE research (Kuehn 2000) shows that, for design duct velocities below the traditional 7.5 m/s threshold, grease deposition was not increased. NFPA *Standard* 96 had historically required a minimum duct velocity of 7.62 m/s. The common belief was that if the duct velocity were lowered, a higher percentage of grease would accumulate on the ductwork, which would then require more frequent duct cleaning. However, no data or research could be identified to support this assumption. Therefore, ASHRAE Research Project RP-1033 (Kuehn 2000) was undertaken to determine the true effect of duct velocity on grease deposition.

The project analyzed grease deposition as a function of mean duct velocity, using octanoic acid (commonly found in cooking oils and other foods). This project confirmed that grease deposition on ductwork is a function of three components: turbulence, thermophoresis, and gravitational settling. Turbulence is a function of grease particle velocity, particle size, and interactions of exhaust air with duct walls. Thermophoresis is caused by a temperature difference between the exhaust airstream and the duct walls and, in simple terms, accounts for grease condensing on the duct walls. Gravitational settling accounts for the effect of gravity. In vertical ductwork that is insulated or relatively adiabatic, turbulence is the determining factor for whether grease accumulates on ductwork walls, and can be accounted for using the deposition velocity. RP-1033 found that if duct velocity is decreased in an insulated duct, grease deposition on all sides of the duct is decreased. Figure 32 shows the deposition velocity of grease particles on the side of the ductwork at different exhaust airflows.

Another significant finding in the study was that, if there is a large temperature gradient between exhaust air inside the duct and the external duct wall, the rate of grease deposition increases significantly. Therefore, duct insulation should be considered where there are large temperature variations.

These results led to NFPA *Standard* 96 changing its minimum duct velocity requirements from 7.62 m/s to 2.54 m/s. This requirement has also been incorporated by the IMC (ICC 2006).

The primary implication for this change is to reduce restaurant energy consumption by reducing exhaust airflow during idle periods, while maintaining necessary capture and containment. This reduces exhaust fan energy consumption and replacement air energy requirements by changing exhaust airflows during cooking and idle periods of the day. Previously, if a restaurant remodeled their cooking operation and reduced the exhaust airflows, the owner had to install smaller-diameter ductwork to meet the 7.6 m/s requirement, which was costly. Now, if a system is designed for heavy-duty equipment, and instead lighter-duty equipment is installed, exhaust airflows can be reduced without the expense of modifying ductwork.

From a design perspective, it is recommended that most kitchens be designed for an in-duct velocity between 7.6 and 9.1 m/s. This allows for reducing the airflows to 2.5 m/s if needed in the future.

FIRE PROTECTION

The combination of flammable grease and particulates carried by kitchen ventilation systems and the potential of cooking equipment to be an ignition source creates a higher hazard level than normally found in HVAC systems. Design of an exhaust system serving cooking equipment that may produce grease-laden vapors must provide, at a minimum, a reasonable level of protection for the safety of building occupants and fire fighters. The design can be enhanced to provide extra protection for property.

Replacement air systems, air-conditioning systems serving a kitchen, and exhaust systems serving only cooking equipment that does not produce grease-laden vapor have no specific fire protection requirements beyond those applicable to similar systems not located in kitchens. However, an exhaust system serving any grease-producing cooking equipment must be considered a grease exhaust system even if it also serves non-grease-producing equipment.

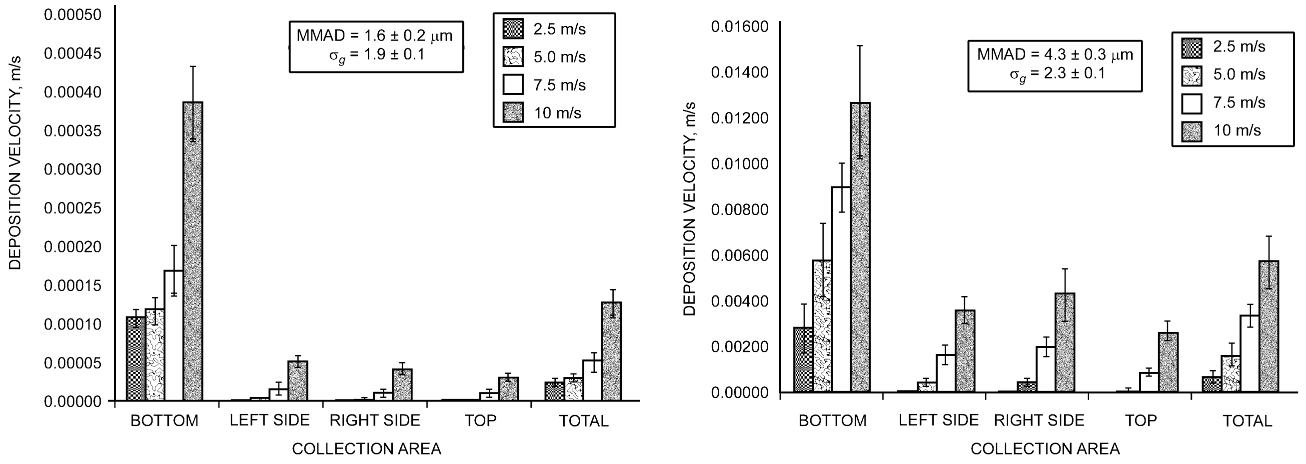
Fire protection starts with proper operation and maintenance of the cooking equipment and the exhaust system. After that, the two primary aspects of fire protection in a grease exhaust system are (1) to extinguish a fire quickly once it has started and (2) to prevent the spread of fire from or to the grease exhaust system.

Fire Suppression

NFPA *Standard* 96 requires that exhaust systems serving grease-producing equipment must include a fire-extinguishing system, which must protect cooking surfaces, hood interior, hood filters or grease extractors, ducts, and any other grease-removal devices in the system. The most common fire-extinguishing systems are wet chemical and water spray systems.

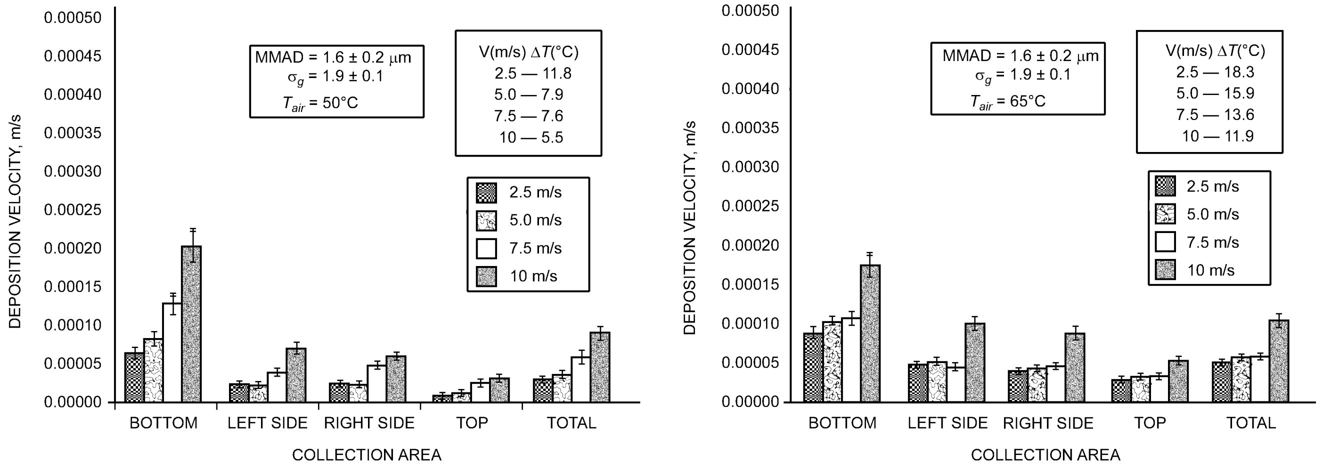
Operation. Actuation of any fire-extinguishing system should not depend on normal building electricity. If actuation relies on electricity, it should be supplied with standby power.

Any extinguishing system must automatically shut off all supplies of fuel and heat to all equipment protected by that system. Any gas appliance not requiring protection but located under the same ventilating equipment must also be shut off. On operation of a wet chemical or water fire-extinguishing system, all electrical sources located under the ventilating equipment, if subject to exposure to discharge from the fire-extinguishing system, must be shut off. If



(A) MMAD = 4.3 μm, ISOTHERMAL CONDITIONS

(B) MMAD = 1.6 μm, ISOTHERMAL CONDITIONS



(C) MMAD = 1.6 μm, EXHAUST AIR TEMPERATURE = 50°C

(D) MMAD = 1.6 μm, EXHAUST AIR TEMPERATURE = 65°C

Fig. 32 Deposition Velocity of Polydispersed Particles on Internal Surfaces of Horizontal Square Exhaust Duct Versus Mean Exhaust Velocity

(Kuehn 2000; MMAD = mass mean aerodynamic diameter)

the hood is in a building with a fire alarm system, actuation of the hood extinguishing system should send a signal to the fire alarm.

Dry and Wet Chemical Systems. Wet chemical fire-extinguishing systems are the most common in new construction for protecting hoods and exhaust systems. Dry chemical systems were popular; however, most manufacturers have removed them from the market because they have not passed UL *Standard* 300. Dry chemical systems are covered in NFPA *Standard* 17, and wet chemical systems are covered in NFPA *Standard* 17A. Both standards provide detailed application information. Systems are tested for their ability to extinguish fires in cooking operations in accordance with UL *Standard* 300. To date, only wet chemical systems are listed to UL *Standard* 300.

Both dry and wet chemicals extinguish a fire by reacting with fats and grease to **saponify**, or form a soapy foam layer that prevents oxygen from reaching the hot surface. This suppresses the fire and prevents reignition. Saponification is particularly important with deep fat fryers, where the frying medium may be hotter than its autoignition temperature for some time after the fire is extinguished. If the foam layer disappears or is disturbed before the frying medium has cooled below its autoignition temperature, it can reignite.

Frying media commonly used today have autoignition points of about 360 to 375°C when new. Contamination through normal use lowers the autoignition point. The chemical agent that extinguishes the fire also contaminates the frying medium, which can further reduce the autoignition point by 30 to 35 K. One advantage of wet chemical systems over dry chemical systems is that the wet chemical provides extra cooling to the frying medium, so that it falls below the autoignition point more quickly.

For a chemical system protecting the entire exhaust system, fire-extinguishing nozzles are located over the cooking equipment being protected, in the hood to protect grease-removal devices and the hood plenum, and at the duct collar (downstream from any fire dampers) to protect ductwork. The duct nozzle is rated to protect an unlimited length of ductwork, so additional nozzles are not required further downstream in the ductwork. Fire detection is required at the entrance to each duct (or ducts, in hoods with multiple duct takeoffs) and over each piece of cooking equipment that requires protection. The detector at the duct entrance may also cover the piece of cooking equipment directly below it.

Chemical fire-extinguishing systems are available as listed, pre-engineered (packaged) systems. Chemical systems typically consist of one or more tanks of chemical agent (dry or wet), a propellant gas, piping to the suppression nozzles, fire detectors, and auxiliary equipment. The fire detectors are typically fusible links that melt at a set temperature associated with a fire, although electronic devices are also available. Auxiliary equipment may include manual pull stations, gas shutoff valves (spring-loaded or solenoid-actuated), and auxiliary electric contacts.

Actuation of dry and wet chemical suppression systems is typically completely mechanical, requiring no electric power. Fire detectors are typically interconnected with the system actuator by steel cable in tension, so that melting of any fusible links releases the tension on the steel cable, causing the actuator to release the propellant and suppressant. The total length of the steel cable and the number of pulley elbows permitted are limited. A manual pull station is typically connected to the system actuator by steel cable. If a mechanical gas valve is used, it is also connected to the system actuator by steel cable. System actuation also switches auxiliary dry electrical contacts, which can be used to shut off electrical cooking equipment, operate an electric gas valve, shut off a replacement air fan, and/or send an alarm signal to the building fire alarm system.

Manual pull stations are generally required to be at least 3 m from the cooking appliance and in a path of egress. Some authorities may prefer that the pull station be installed closer to the cooking equipment, for faster response; however, if it is too close, it may not be possible to approach it once a fire has started. Refer to the applicable code requirements for each jurisdiction to determine specific requirements for location and mounting heights of pull stations.

Water Systems. Water can be used for protecting cooking appliances, hoods, and grease exhaust systems. Standard fire sprinklers may be used throughout the system, except over deep-fat fryers, where special automatic spray nozzles specifically listed for the application must be used. These nozzles must be aimed properly and supplied with the correct water pressure. Many hood manufacturers market a pre-engineered water spray system that typically includes a cabinet containing the necessary plumbing and electrical components to monitor the system and initiate fuel shutoff and building alarms.

Application of standard fire sprinklers for protection of cooking appliances, hoods, and grease exhaust systems is covered by NFPA *Standard* 13. NFPA *Standards* 25 and 96 covers maintenance of sprinkler systems serving an exhaust system. The sprinklers must connect to a wet-pipe building sprinkler system installed in compliance with NFPA *Standard* 13.

Water systems that spray a fine mist can be used to protect cooking equipment. Nozzles protecting deep fat fryers must be specifically listed for this use. The water spray suppresses the fire in two ways: the mist spray absorbs heat from the fire, and then becomes steam, which displaces air and suffocates the fire.

Although standard sprinklers may be used to protect cooking equipment other than deep-fat fryers, care must be taken to ensure that sprinklers are properly selected for a fine mist discharge; if pressure is too high or the spray too narrow, the water spray could push flames off the cooking equipment.

One advantage of a sprinkler system is that it has virtually unlimited capacity, whereas chemical systems have limited chemical supplies. This can be an advantage in suppressing a fire, but all the water must be safely removed from the space. Where sprinklers are used in ducts, the ductwork should be pitched to drain safely. NFPA *Standard* 13 requires that sprinklers used to protect ducts be installed every 3 m on center in horizontal ducts, at the top of every vertical riser, and in the middle of any vertical offset. Any sprinklers exposed to freezing temperatures must be protected.

Hoods that use water either for periodic cleaning (water-wash) or for grease removal (cold water mist) can use this feature in conjunction with the fire-extinguishing system to protect the hood, grease-removal device, and/or ducts in the event of a fire. The water supply for these systems may be from the kitchen water supply if flow and pressure requirements are met. These hoods can also act as a fire stop because of their multipass configuration and the fact that the grease extractors are not removable.

Combination Systems. Different system types may protect different parts of the grease exhaust system, as long as the entire system is protected. Examples include (1) an approved water-wash or water mist system to protect the hood in combination with a dry or wet chemical system to protect ducts and the cooking surface or (2) a chemical system in the hood backed up by water sprinklers in the ductwork. Combination systems are more common in multiple-hood systems, where a separate extinguishing system may be used to protect a common duct. If combination systems will discharge their suppressing agents together in the same place, the agents must be compatible.

Multiple-Hood Systems. All hoods connected to a multiple-hood exhaust system must be on the same floor of the building to prevent the spread of fire through the duct from floor to floor. Preferably, there should be no walls requiring greater than a 1 h fire resistance rating between hoods.

The multiple-hood exhaust system must be designed to (1) prevent a fire in one hood or in the duct from spreading through the ducts to another hood and (2) protect against a fire starting in the common ductwork. Of course, the first line of protection for the ducts is keeping it clean. Especially in a multiple-tenant system, a single entity must assume responsibility for cleaning the common ductwork frequently.

Each hood must have its own fire-extinguishing system to protect the hood and cooking surface. A single system could serve more than one hood, but in the event of fire under one hood, the system would discharge its suppressant under all hoods served, resulting in unnecessary cleanup expense and inconvenience. A water-mist system could serve multiple hoods if sprinkler heads were allowed to operate independently.

Because of the possibility of a fire spreading through ducts from one hood to another, the common ductwork must have its own fire protection system. The appendices of NFPA *Standards* 17 and 17A present detailed examples of how common ducts can be protected either by one system or by a combination of separate systems serving individual hoods. Different types of fire-extinguishing systems may be used to protect different portions of the exhaust system; however, in any case where two different types of system can discharge into the common duct at the same time, the agents must be compatible.

As always, actuation of the fire-extinguishing system protecting any hood must shut off fuel or power to all cooking equipment under that hood. When a common duct, or portion thereof, is protected by a chemical fire-extinguishing system that activates from a fire in a single hood, NFPA *Standards* 17 and 17A require shutoff of fuel or power to the cooking equipment under every hood served by that common duct, or portion of it protected by the activated system, even if there was no fire in the other hoods served by that duct.

From an operational standpoint, it is usually most sensible to provide one or more fire-extinguishing systems to detect and protect against fire in common ducts and a separate system to protect each hood and its connecting ducts. This (1) prevents a fire in the common duct from causing discharge of fire suppressant under an unaffected hood and (2) allows unaffected hoods to continue operation in the event of a fire under one hood unless the fire spreads to the common duct.

Preventing Fire Spread

The exhaust system must be designed and installed both to prevent a fire starting in the grease exhaust system from damaging the building or spreading to other building areas and to prevent a fire in one building area from spreading to other parts of the building via the grease exhaust system. This protection has two main aspects: (1) maintaining clearance from the duct to other portions of the building and (2) enclosing the duct in a fire-resistance-rated enclosure. Both aspects are sometimes addressed by a single action.

Clearance to Combustibles. A grease exhaust duct fire can generate gas temperatures of 1100°C or greater in the duct. In such a grease fire, heat radiating from the hot duct surface can ignite combustible materials near the duct. Most codes require a minimum clearance of 460 mm from the grease exhaust duct to any combustible material. However, even 460 mm may not be sufficient clearance to prevent ignition of combustibles in the case of a major grease fire, especially in larger ducts.

Several methods to protect combustible materials from the radiant heat of a grease duct fire and permit reduced clearance to combustibles are described in NFPA *Standard* 96. Previous editions required that these protections be applied to the combustible material rather than to the duct, on the theory that if the duct is covered with an insulating material, the duct itself will become hotter than it would if it were free to radiate its heat to the surroundings. The hotter temperatures could result in structural damage to the duct. NFPA *Standard* 96 now allows materials to be applied to the actual duct. However, because this edition may not have been accepted by some jurisdictions, the authority having jurisdiction should be consulted before clearances to combustible materials are reduced.

Listed grease ducts, typically double-wall ducts with or without insulation between the walls, may be installed with reduced clearance to combustibles in accordance with manufacturers' installation instructions, which should include specific information regarding the listing. Listed grease ducts are tested under UL *Standard* 1978.

NFPA *Standard* 96 also requires a minimum clearance of 75 mm to "limited combustible" materials (e.g., gypsum wallboard on metal studs). At present, none of the standards and model codes requires any clearance to noncombustible materials except for enclosures.

Enclosures. Normally, when a duct penetrates a fire-resistance-rated wall or floor, a fire damper is used to maintain the integrity of the wall or floor. Because fire dampers may not be installed in a grease exhaust duct unless specifically approved for such use, there must be an alternative means of maintaining the integrity of rated walls or floors. Therefore, grease exhaust ducts that penetrate a fire-resistance-rated wall or floor-ceiling assembly must be continuously enclosed in a fire-rated enclosure from the point the duct penetrates the first fire barrier until the duct leaves the building. Listed grease ducts are also subject to these enclosure requirements. The requirements are similar to those for a vertical shaft (typically 1 h rating if the shaft penetrates fewer than three floors, 2 h rating if it penetrates three or more floors), except that the shaft can be both vertical and horizontal. In essence, the enclosure extends the room containing the hood through all the other compartments of the building without creating any unprotected openings to those compartments.

Where a duct is enclosed in a rated enclosure, whether vertical or horizontal, clearance must be maintained between the duct and the shaft. NFPA *Standard* 96 and IMC (ICC 2006a) require minimum 150 mm clearance and that the shaft be vented to the outside. IMC requires that each exhaust duct have its own dedicated enclosure.

Some listed grease ducts are designed and tested for use without shaft enclosure. Listed grease ducts of this type typically incorporate integral fire protection, which serves the same function as the shaft enclosure. These products are tested and listed in accordance with UL *Standard* 2221. They must be installed in strict compliance with the manufacturer's installation instruction.

Some available materials are listed to serve as a fire-resistance-rated enclosure for a grease duct when used to cover a duct directly with minimal clear space between the duct and the material. These materials are tested and listed in accordance with ASTM *Standard* E2336 or the International Code Council (ICC 2004). These listed materials must be applied in strict compliance with the manufacturer's installation instructions, which may limit the size of duct to be covered and specify required clearances for duct expansion and other installation details. When a duct is directly covered with an insulating material, there is a greater chance of structural damage to the duct from the heat of a severe fire. Structural integrity of exhaust ducts should be assessed after any serious duct fire.

Insulation materials that have not been specifically tested and approved for use as fire protection for grease exhaust ducts should not be used in lieu of rated enclosures or to reduce clearance to combustibles. Even insulation approved for other fire-protection applications, such as to protect structural steel, may not be appropriate for grease exhaust ducts because of the high temperatures that may be encountered in a grease fire.

The IMC (ICC 2006a) requires that listed grease ducts installed without shaft enclosure be tested and listed in accordance with UL *Standard* 2221. Likewise, grease duct enclosure materials must be tested and listed in accordance with ASTM *Standard* E2336.

Exhaust and Supply Fire-Actuated Dampers. Because of the risk that the damper may become coated with grease and become a source of fuel in a fire, balancing and fire-actuated dampers are not permitted at any point in a grease exhaust system except where specifically listed for each use or required as part of a listed device or system. Typically, fire dampers are found only at the hood collar and only if provided by the manufacturer as part of a listed hood.

Opinions differ regarding whether any fire-actuated dampers should be provided in the exhaust hood. On one hand, a fire-actuated damper at the exhaust collar may prevent a fire under the hood from spreading to the exhaust duct. However, like anything in the exhaust airstream, the fire-actuated damper and linkage may become coated with grease if not properly maintained, which may impede damper operation. On the other hand, without fire-actuated dampers, the exhaust fan will draw smoke and fire away from the hood. Although this cannot be expected to remove all smoke from the kitchen during of a fire, it can help to contain smoke in the kitchen and minimize migration of smoke to other areas of the building.

A fire-actuated damper will generally close only in the event of a severe fire; most kitchen fires are extinguished before enough heat is released to trigger the fire-actuated damper. Thus the hood fire-actuated damper remains open during relatively small fires, allowing the hood to remove smoke, but can close in the event of a severe fire, helping to contain the fire in the kitchen area.

Fan Operations. If it is over 940 L/s, the replacement air supply to the kitchen is generally required to be shut down during fire to avoid feeding air to the fire. However, if the exhaust system is intended to operate during a fire to remove smoke from the kitchen (as opposed to just containing it in the kitchen), the replacement air system must operate as well. If the hood has an integral replacement air plenum, a fire-actuated damper must be installed in the replacement air collar to prevent a fire in the hood from entering the replacement air ductwork. NFPA *Standard* 96 details the instances where fire-actuated dampers are required in a hood replacement air assembly.

Regardless of whether fire-actuated dampers are installed in the exhaust system, NFPA *Standard* 96 calls for the exhaust fan to continue to run in the event of a fire unless fan shutdown is required by a listed component of the ventilating system or of the fire-extinguishing system. Dry and wet chemical fire-extinguishing systems protecting ductwork are tested both with and without airflow; exhaust airflow is not necessary for proper operation.

OPERATION AND MAINTENANCE

Operation

All components of the ventilation system are designed to operate in balance with each other, even under variable loads, to properly capture, contain, and remove cooking effluent and heat and maintain proper space temperature control in the most efficient and economical manner. Deterioration in any of these components unbalances the system, affecting one or more of its design concepts. The system design intent should be fully understood by the operator so that any deviations in operation can be noted and corrected. In addition to creating health and fire hazards, normal cooking effluent deposits can also unbalance the system, so they must be regularly removed.

All components of exhaust and replacement air systems affect proper capture, containment, and removal of cooking effluent. In the exhaust system, this includes the cooking equipment itself, exhaust hood, all filtration devices, ducts, exhaust fan, and any dampers. In the replacement air system, this includes the air-handling unit(s) with intake louvers, dampers, filters, fan wheels, heating and cooling coils, ducts, and supply registers. In systems that obtain their replacement air from the general HVAC system, this also includes return air registers and ducts.

When the system is first set up and balanced in new condition, these components are set to optimum efficiency. In time, all components become dirty; filtration devices, dampers, louvers, heating and cooling coils, and ducts become restricted; fan blades change shape as they accumulate dirt and grease; and fan belts loosen. In addition, dampers can come loose and change position, even closing, and ducts can develop leaks or be blocked if internal insulation sheets fall down.

All these changes deteriorate system performance. The operator should know how the system performed when it was new, to better recognize when it is no longer performing the same way. This knowledge allows problems to be found and corrected sooner and the peak efficiency and safety of system operation to better be maintained.

Maintenance

Maintenance may be classified as preventive or emergency (breakdown). **Preventive maintenance** keeps the system operating as close as possible to optimal performance, including maximum production and least shutdown. It is the most effective maintenance and is preferred.

Preventive maintenance can prevent most emergency shutdowns and emergency maintenance. It has a modest ongoing cost and fewer unexpected costs. Clearly the lowest-cost maintenance in the long run, it keeps the system components in peak condition, extending the operating life of all components.

Emergency maintenance must be applied when a breakdown occurs. Sufficient staffing and money must be applied to the situation to bring the system back on line in the shortest possible time. Such emergencies can be of almost any nature. They are impossible to predict or address in advance, except to presume the type of component failures that could shut the system down and keep spares of these components on hand or readily accessible, so they can be quickly replaced. Preventive maintenance, which includes regular inspection of critical system components, is the most effective way to avoid emergency maintenance.

Following are brief descriptions of typical operations of various components of kitchen ventilation systems and the type of maintenance and cleaning required to bring the abnormally operating system back to normal. Many nontypical operations are not listed here.

Cooking Equipment

Normal Operation. Produces properly cooked product, of correct temperature, within expected time. Minimum smoke during cooking.

Abnormal Operation. Produces undercooked product, of lower temperature, with longer cooking times. Increased smoke during cooking.

Cleaning/Maintenance. Clean solid cooking surfaces between each cycle if possible, or at least once a day. Baked-on product insulates and retards heat transfer. Filter frying medium daily and change it on schedule recommended by supplier. Check that (1) fuel source is at correct rating, (2) thermostats are correctly calibrated, and (3) conditioned air is not blowing on cooking surface.

Solid-fuel appliances are listed as “Extra-Heavy Duty” (see Table 1) and require additional attention. A hood over a solid-fuel appliance must be individually vented and therefore not be combined at any point with another duct and fan system. Using a UL *Standard* 762 upblast, in-line, or utility set fan listed to 205 to 260°C is suggested because the airstream temperature may be hotter without cooler air combining from other, typically lower-temperature cooking appliances. Design, installation, and maintenance precautions for the use of and emissions from solid fuel include monthly duct cleaning with weekly inspections, spark arrestors, and additional spacing to fryers. Refer to NFPA *Standard* 96, Chapters 5 to 10 and 14, and IMC sections 507 and 906, for additional direction.

Exhaust Systems

Normal Operation. All cooking vapors are readily drawn into the exhaust hood, where they are captured and removed from the space. The environment immediately around the cooking operation is clear and fresh.

Abnormal Operation. Many cooking vapors do not enter the exhaust hood at all, and some that enter subsequently escape. The environment around the cooking operation, and likely in the entire kitchen, is contaminated with cooking vapors and a thin film of grease.

Cleaning/Maintenance. Clean all grease removal devices in the exhaust system. Hood filters should be cleaned at least daily. For other devices, follow the minimum recommendations of the manufacturer; even these may not be adequate at very high flow rates or with products producing large amounts of effluent. Check that (1) all dampers are in their original position, (2) fan belts are properly tensioned, (3) the exhaust fan is operating at the proper speed and turning in the proper direction, (4) the exhaust duct is not restricted, and (5) the fan blades are clear.

NFPA *Standard* 96 design requirements for access to the system should be followed to facilitate cleaning the exhaust hood, ductwork, and fan. Cleaning should be done before grease has built up to 6 mm in any part of the system, and by a method that cleans to bare metal. Cleaning agents should be thoroughly rinsed off, and all loose grease particles should be removed, because they can ignite more readily. Agents should not be added to the surface after cleaning, because their textured surfaces merely collect more grease more quickly. Fire-extinguishing systems may need to be disarmed before cleaning, to prevent accidental discharge, and then reset by authorized personnel after cleaning. All access panels removed must be reinstalled after cleaning, with proper gasketing in place to prevent grease leaks and escape of fire.

Supply, Replacement, and Return Air Systems

Normal Operation. The environment in the kitchen area is clear, fresh, comfortable, and free of drafts and excessive air noise.

Abnormal Operation. The kitchen is smoky, choking, hot, and humid, and perhaps very drafty with excessive air noise.

Cleaning/Maintenance. Check that the replacement air system is operating and is providing the correct amount of air to the space. If it is not, the exhaust system cannot operate properly. Check that dampers are set correctly, filters and exchangers are clean, the belts are tight, the fan is turning in the correct direction, and supply and return ductwork and registers are open, with supply air discharging in the correct direction and pattern. If drafts persist, the system may need to be rebalanced. If noise persists in a balanced system, system changes may be required.

Filter cleaning or changing frequency varies widely depending on the quantity of airflow and contamination of local air. Once determined, the cleaning schedule must be maintained.

With replacement air systems, the air-handling unit, coils, and fan are usually cleaned in spring and fall, at the beginning of the seasonal change. More frequent cleaning or better-quality filtering may be required in some contaminated environments. Duct cleaning for the system is on a much longer cycle, but local codes should be checked as stricter requirements are invoked. Ventilation systems should be cleaned by professionals to ensure that none of the expensive system components are damaged. Cleaning companies should be required to carry adequate liability insurance. The Power Washers of North America (PWNA) and the International Kitchen Exhaust Cleaning Association (IKECA) provide descriptions of proper cleaning and inspection techniques and lists of their members.

Control Systems (Operation and Safety)

Normal Operation. Control systems should not allow cooking equipment to operate unless both exhaust and replacement air systems are operating and the fire suppression system is armed. With multiple exhaust and replacement air systems, controls maintain the proper balance as cooking equipment is turned on and off. In the event that a fire-suppression system operates, the energy source for the cooking equipment it serves is shut off. On ducted systems, the exhaust fan usually keeps running to remove fire and smoke from building. On ductless systems, the fan may or may not keep running, but a discharge damper closes to keep the flames away from the ceiling. The replacement air system may continue to run, or it may be shut off by a separate local area fire and smoke sensor. If the control system does not operate in this way, changing to this operation should be considered.

Abnormal Operation. Cooking equipment operates when exhaust and supply are turned off, perhaps because the fire suppression system is unarmed or has been bypassed. When extra cooking systems are turned on or off, the operator must remember to manually turn the exhaust and replacement air fans on or off as well.

When exhaust and replacement air systems are not interlocked, the system can be out of balance. This can cause many of the kinds of abnormal operation described for the other systems. With gas-fired cooking equipment, the fire-suppression system may have a false discharge if the exhaust system is not operating. If cooking is allowed when the fire suppression system is inoperable, the chance of a serious fire is greater, and the operator is liable because insurance usually does not cover this situation.

Cleaning/Maintenance. Cleaning is usually restricted to mechanical operators and electrical sensors in the fire-suppression system and within the hood that are exposed to grease. If they become excessively coated with grease, mechanical operators cannot move and sensors cannot sense. The result is decreased control and safety. The mechanical operators should be cleaned as often as required to maintain free movement. Fire-suppression system operators may need to be changed annually rather than cleaned. Check with a local fire-suppression system dealer before attempting to clean any of these components.

Maintaining control systems (presuming they were properly designed) is mostly a matter of checking the performance of the entire system regularly (min. every 3 months) to ensure it is still performing as designed. Mechanical linkages on dampers and cleanliness of sensors should be checked regularly (min. once a month). All electrical screw terminals in the components should be checked for tightness, relay contacts should be checked for cleanliness, and all exposed conducting surfaces should be checked for corrosion on an annual basis.

RESIDENTIAL KITCHEN VENTILATION

Although commercial and residential cooking processes are similar, their ventilation requirements and procedures are different. Differences include exhaust airflow rate and installation height. In addition, residential kitchen ventilation is less concerned with replacement air, and energy consumption is comparatively insignificant because of lower airflow, smaller motors, and intermittent operation.

Equipment and Processes

Although the physics of cooking and the resulting effluent are about the same, residential cooking is usually done more conservatively. Heavy-duty and extra-heavy-duty equipment, such as upright broilers and solid-fuel-burning equipment (described in Table 1), is not used. Therefore, the high ventilation rates of commercial kitchen ventilation and equipment for delivering these rates are not often found in residential kitchens. However, some residential kitchens are designed to operate with commercial-type cooking equipment, with higher energy inputs rates than usually found. In these cases, the hood may be similar to a commercial hood, and the required ventilation rate may approach that required for small commercial facilities.

Cooking effluent and by-products of open-flame combustion must be more closely controlled in a residence than in a commercial kitchen, because any escaping effluent can be dispersed throughout a residence, whereas a commercial kitchen is designed to be negatively pressurized compared to surrounding spaces. A residence also has a much lower background ventilation rate, making escaped contaminant more persistent. This situation makes residential kitchen ventilation a different kind of challenge, because problems cannot be resolved by simply increasing the ventilation rate at the cooking process.

Residential cooking always produces a convective plume that carries with it cooking effluent, often including grease vapor and particles, as well as water vapor, and by-products of combustion when natural gas is the energy source. Sometimes there is spatter as well, but those particles are so large that they are not removed by ventilation. Residential kitchen hoods depend more on thermal buoyancy than mechanical exhaust to capture cooking effluent and by-products of combustion.

Hoods and Other Ventilation Equipment

Wall-mounted, conventional range hoods ventilate most residential kitchens. Overall, they do the best job at the lowest installed cost. There are unlimited style-based variations of the conventional range hood shape. Deep canopy hoods are somewhat more effective because of their capture volume. Other styles have less volume, or a more flat bottom, and may be somewhat less effective at capturing effluent. To the extent that residential range hoods are often mounted between cabinets, with portions of the cabinets extending below the sides of the hood, performance may be improved because the cabinet sides help contain and channel the exhaust flow into the hood.

An increasingly popular development in residential kitchen ventilation is using a ventilating microwave oven in place of the typical residential range hood. Microwave ovens used for this purpose typically include small mesh filters mounted on the bottom of the oven and an internal exhaust fan. Means are usually provided to direct the exhaust flow in two directions: back into the kitchen or upward to an exhaust duct leading outdoors. The latter is more expensive but highly preferred; otherwise, if directed back to the kitchen, walls, ceiling, and cabinet surfaces are likely to become coated with grease from condensed grease vapor, and grease residue can damage paint and varnish. Additionally, typical microwave oven ventilators do not include vertical surfaces that provide a reservoir volume to contain the convective plume during transient effects, such as removing the lid from a cooking vessel. Consequently, microwave oven ventilators often provide lower exhaust capture and containment performance than standard range hoods.

Downdraft range-top ventilators have also become more popular. Functionally, these are an exception, because they capture contaminants by producing velocities over the cooking surface greater than those of the convective plume. With enough velocity, their operation can be satisfactory; however, velocity may be limited to prevent adverse effects such as gas flame disturbance and cooking process cooling. Additionally, this method is more effective for exhaust from cooking near the range surface, and it is usually much less effective for capturing the convective plume from taller cooking vessels, because the convective plume is too far above the ventilator intake to be affected by it.

Ironically, many high-end kitchens have less efficient ventilation than standard range hoods. Inefficient methods include

- Mounting range tops in cooking islands with no exhaust hood or other means of ventilation
- Mounting ovens in cabinets, separate from rangetops, without any way to remove heat and effluents from the oven
- Using low-profile exhaust devices with insufficient overhang over the appliance and no reservoir to contain convective plume during dynamic effects
- Having duct runs, particularly in larger homes, with very high static pressure losses, so that the actual exhaust flow rate is much lower than the nominal exhaust fan rating

Whole-kitchen exhaust fans were more common in the past, but they are still used. Mounted in the kitchen wall or ceiling, they ventilate the entire kitchen volume rather than capturing contaminants at the source. For kitchen exhaust fans not above the cooking surface, and without a capturing hood, 15 air changes per hour (ach) is recommended; for ceiling-mounted fans, this is usually sufficient, but for wall-mounted fans, it may be marginal.

Residential exhaust hoods are often furnished with multiple-speed fans, so that users can match exhaust fan speeds (and noise) with the cooking process and resultant convective plume. Carrying this concept further, at least one high-end residential exhaust hood manufacturer provides an automatic two-speed control that increases fan speed when higher convective plume temperature is sensed.

Continuous low-level, whole-building ventilation is increasingly used to ensure good indoor air quality in modern, tightly built houses with less infiltration. ASHRAE *Standard* 62.2 requires kitchen ventilation in most residences. Some whole-building ventilation systems can intermittently increase airflow to achieve the needed reduction in cooking effluent. In that case, there must be provision to avoid introducing and accumulating grease and other cooking effluent that may cause undesirable growth of microorganisms.

Differences Between Commercial and Residential Equipment

Residential hoods usually meet UL *Standard* 507 requirements. Fire-actuated dampers are never part of the hood and are almost never used. Grease filters in residential hoods are much simpler, and grease collection channels are rarely used because inadequate maintenance could allow grease to pool, creating a fire and health hazard.

Conventional residential wall hoods usually have standard dimensions that match the standard 75 mm modular grid of residential cabinets. Heights of 150, 230, 300, and 610 mm are common, as are depths from 430 to 560 mm. Width is usually the same as the cooking surface, with 760 mm width nearly standard in the United States. Current U.S. Housing and Urban Development (HUD) Manufactured Home Construction and Safety Standards call for 75 mm overhang per side.

Hood mounting height is usually 460, 610, or 760 mm, and sometimes even higher with a sacrifice in collection efficiency. A lower-mounted hood captures more effectively because there is less opportunity for lateral air currents to disrupt the convective plume. Studies show 460 mm is the minimum height for cooking surface access. Some codes require a minimum of 760 mm from the cooking surface to combustible cabinets. In that case, the bottom of a 150 mm hood can be 610 mm above the cooking surface.

A minimum airflow rate (exhaust capacity) of 60 L/s per linear metre of hood width has long been recommended by the Home Ventilating Institute (HVI 2004), and confirmed by field tests. Additional capacity, with speed control, is desirable for handling unusually vigorous cooking and cooking mistakes, because airflow can be briefly increased to clear the air, and speed can be reduced to a quieter level for normal cooking.

Exhaust Duct Systems

Residential hoods offer little opportunity for custom design of an exhaust system. The range hood has a built-in duct connector and the duct should be the same size, whether round or rectangular. A hood includes either an axial or a centrifugal fan. The centrifugal fan can develop higher pressure, but the axial fan is usually adequate for low-volume hoods. The great majority of residential hoods in the United States have HVI-certified airflow performance. In all cases, it is highly preferable to vent the exhaust hood outdoors through a roof cap, rather than venting into the attic or back into the home, whether into the kitchen or elsewhere.

Replacement (Makeup) Air

The exhaust rate of residential hoods is generally low enough and natural infiltration sufficient to avoid the need for replacement air systems. Although this may cause slight negative pressurization of the residence, it is brief and is usually less than that caused by other equipment. Still, backdrafts through the flue of a combustion appliance should be avoided and residences with gas furnace and water heater should have the flue checked for adequate flow. NFPA *Standard* 54 provides a method of testing flues for adequate performance. Sealed-combustion furnaces and water heaters are of less concern.

Sometimes commercial-style cooking equipment approved for residential use is installed in residences. For the higher ventilation requirements, see earlier sections of this chapter, especially the section on Replacement (Makeup) Air Systems.

Energy Conservation

The energy cost of residential hoods is quite low because of the few annual running hours and the low rate of exhaust. For example, it typically costs less than $10 per heating season in Chicago to run a hood and heat replacement air, based on running at 70 L/s for an hour a day and using gas heat.

Fire Protection for Residential Hoods

Residential hoods must be installed with metal (preferably steel) duct, positioned to prevent grease pooling. Residential hood exhaust ducts are almost never cleaned, and there is no evidence that this causes fires.

There have been some attempts to make fire extinguishers available in residential hoods, but none has met with broad acceptance. However, grease fires on the residential cooking surface continue to occur, almost always the result of unattended cooking. There is no industry-accepted performance standard or consistency of design in residential fire-extinguishing equipment.

Maintenance

All UL-listed hoods and kitchen exhaust fans are designed for cleaning, which should be done at intervals consistent with the cooking practices of the user. Although cleaning is sometimes thought to be for fire prevention, the health benefits of removing nutrients available for the growth of organisms can be more important.

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