Related Commercial Resources

CHAPTER 34. KITCHEN VENTILATION

THIS chapter focuses primarily on commercial kitchen ventilation (CKV) systems in restaurants and institutional food service facilities, and incorporates the research and experience (including all steps of the design process) amassed by TC 5.10 over the past two decades. Although a brief section on residential kitchen ventilation has been retained, only minor updates have been incorporated over the history of this chapter. Given ongoing debate on residential range hood performance, TC 5.10 anticipates sponsoring research to provide a basis for enhanced design of residential kitchen ventilation (RKV) systems.

To provide a means for codifying critical CKV items as well as provide expertise to code-writing authorities, TC 5.10 sponsors Standing Standard Project Committee (SSPC) 154, Ventilation for Commercial Cooking Operations. SSPC-154's scope includes providing the most complete design guidance available on commercial kitchen ventilation components and systems. Specific areas include kitchen hoods, exhaust systems, and replacement air systems.

SSPC-154 relies on the significant field experiences of the manufacturers, designers, and users of kitchen ventilation systems. ASHRAE *Standard* 154 is intended to serve as a template for standardization, harmonization, and ongoing revision of related model and adopted codes and to bring consistency to design requirements and applications of commercial kitchen ventilation systems.

1. COMMERCIAL KITCHEN VENTILATION

Kitchen ventilation is a complex web of interconnected HVAC systems. The main components typically include (1) cooling to address heat from cooking appliances, (2) replacement air to provide proper pressurization during cooking operations, and (3) exhaust to remove heat and effluent generated by cooking appliances. 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 and retail malls (see Chapter 2), hotels (Chapter 7), hospitals (Chapter 9), single- and multifamily dwellings (Chapter 1), educational facilities (Chapter 8), and correctional facilities. Each building type has special requirements for its kitchens, but many basic needs are common to all. This chapter provides an understanding of the different components of kitchen ventilation systems and where they can be applied. Additionally, background information is included to provide an understanding of the history and rationale behind these design decisions.

Kitchen ventilation has at least two purposes: (1) to provide a comfortable environment in the kitchen and (2) to ensure 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. Kitchen ventilation ensures safety by providing the means to remove heat, smoke, and grease (cooking effluent) produced during normal cooking operations.

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.

The centerpiece of almost any kitchen ventilation system is an exhaust hood(s), 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. Finally, note that the arrangement of food service equipment and its coordination with the hood(s) can greatly affect the energy used by these systems, which in turn affects kitchen operating costs. Quite often, the hood selection and appliance layout is determined by a kitchen facility designer. To minimize energy use and ensure a properly designed kitchen ventilation system, the HVAC engineer should reach out to the kitchen designer and share the practices and ideas presented in this chapter.

SUSTAINABILITY

Kitchens are some of the most intensive users of energy for a given floor area when compared to other commercial or institutional occupancies. In addition to energy used during cooking, the kitchen ventilation system must address the large amount of heat emitted or convected into the kitchen from the cooking equipment, and supply and condition the replacement air needed to support the cooking effluent exhaust system as well as ensure acceptable indoor environmental quality (IEQ). An additional factor to be considered is the cooking effluent, and any treatments that may be required before it is discharged into the atmosphere.

Given these factors, it is imperative that the kitchen ventilation system be designed with careful consideration of both first costs and operating costs. Maintenance costs should also be considered, including scheduled equipment service and replacement (e.g., hoods and exhaust duct cleaning, hood filter cleaning, fire protection system inspection, charging, refusing), any corresponding labor, and any production downtime as a result of the maintenance.

To ensure all of these criteria are accounted for in the kitchen ventilation design, the integrated building design approach described in Chapter 60 is recommended.

1.1 COMMISSIONING

Because CKV systems are very complex operational environments, it is strongly recommended that ASHRAE *Standard* 202 and the guidance in Chapter 44 be followed for any commercial kitchen ventilation project. Sections of this chapter contain the technical information necessary to address all four phases of commissioning. Addressing the following topics is recommended when developing and executing any commissioning plan:

1. Owners project requirements (OPR)
   a. System manual outline
      i. System selection: specific kitchen ventilation use requirements (by owner or design team)
      ii. Type of facility (e.g., commissary, quick service, full service, institutional)
      iii. Cooking appliances selection based on menu, type of cooking, and special/unusual considerations
      iv. Other considerations
         A. System cost
         B. Kitchen space comfort targets
         C. Energy use and sustainability targets
         D. Replacement air requirements
         E. Cooking exhaust
            I. Duct routing and egress
            II. Effluent control requirements
            III. Air discharge and outlet restrictions
         F. Other mechanical services
            I. HVAC equipment location
            II. Utility services
         G. Future expansion
         H. Ongoing maintenance requirements
2. Design phase
   a. Systems manual outline (i.e., design intent): the engineer’s response to the OPR
   b. Hood selection based on appliance line up (*very critical because it affects exhaust rate*)
   c. Replacement air method, and kitchen air movement
   d. Accounting for kitchen equipment heat gains
   e. System control strategies, including demand-controlled kitchen ventilation (DCKV) systems
   f. Exhaust effluent control measures
   g. Energy saving measures
   h. Exhaust system requirements

   i. Fire safety
   j. Codes and standards
      i. NFPA *Standard* 96
      ii. ASHRAE *Standard* 154
      iii. IMC (ICC 2018)
      iv. UL *Standard* 710
      v. UL *Standard* 762
3. Construction phase
   a. Submittal review and coordination with all disciplines
   b. Installation and execution with end use in mind
   c. Exhaust duct construction
   d. Air outlet and inlet locations and adjustments
   e. Technical commissioning of the following:
      i. System controls for replacement air and exhaust air, including DCKV systems
      ii. Cooking effluent control equipment
      iii. Cooking fire suppression systems
      iv. Air system testing, balancing, and adjustment
4. Occupancy and operations
   a. Owner and user training of systems
      i. Exhaust and replacement air controls, including DCKV systems
      ii. Cooking effluent control
      iii. Cooking fire suppression
   b. Maintenance schedule
   c. Recommissioning plan
   d. Consequences of any revision/remodel (e.g., changing cooking equipment)

1.2 VENTILATION DESIGN

Design Process

Designing a CKV or even a high-end residential kitchen ventilation system requires a different design approach and process than for most traditional HVAC systems. Design considerations include large replacement air requirements, large internal heat gains, kitchen workers' comfort, minimizing HVAC system energy use, and fire safety, all of which are equally high priorities that must be addressed during system design.

Necessary steps to design the ventilation systems for a commercial kitchen are as follows. Details for each step can be found in the subsequent sections in this chapter, or in the other Handbook chapters.

1. **Kitchen facilities design** (including cooking menu and appliance selection and placement). This design is typically performed by the food service consultant (FSC). Additionally, determine which appliances require an exhaust hood.
2. **Exhaust hood selection**, including exhaust air rates. Often overlooked, but one of the most critical design decisions for any CKV system: hood selection directly affects exhaust rates, the corresponding replacement air requirements, CKV system heat gain and loss calculations, and the system's overall energy use. Considerations include

   a. Appliance duty rating, fuel type (e.g., gas, solid fuel, electric, combination), cooking emission, and thermal plume character
   b. Type I or Type II, based on appliance use or process
   c. Hood style (e.g., canopy, island, back shelf)
   d. Energy saving options (e.g., side panels, extra overhang, demand control kitchen ventilation)
   e. Life-cycle cost analysis
3. **CKV system integration and design.** Determine exactly what the CKV system should accomplish, and how to holistically integrate it into the building.
4. **Replacement air design.** Addresses the need for delivering the replacement air into the kitchen. Considerations include
   a. Transfer air, comfort supply air, or direct makeup air (or any combination)
   b. ASHRAE *Standard* 62.1 compliance
   c. Adjacent zone air classifications
   d. Replacement and supply air delivery systems
5. **CKV system controls.** Maintain pressurization and comfort for the kitchen, dining area, and if applicable any adjoining zones. Accommodate any demand control systems, including DCKV and adjacent zones' demand-controlled ventilation (DCV) system(s).
6. **Heat gain and loss calculations**
   a. Appliance heat gains
   b. Replacement air
7. **Exhaust system design**
   a. Duct type selection
   b. Fire safety
   c. Air discharge
   d. Effluent control devices
   e. Fire suppression
8. **HVAC system design**
   a. Equipment selection
   b. Diffuser and return grille layout (very critical)
9. **Hood and replacement air commissioning specifications** (e.g., air balancing, troubleshooting)

Note: the CKV design engineer is recommended to engage the FSC during steps 1 and 2 to identify areas where both designs can be harmonized for optimal CKV performance.

1.3 SYSTEM INTEGRATION AND DESIGN

Ideally, 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 replacement air system(s) must integrate and balance with the exhaust system and/or facility HVAC system(s). Even optimal system designs require field testing and balancing once installed. It is important to verify compliance with design, and equally important to confirm that the design meets the needs of the operating facility. Air balance is a critical step in any CKV commissioning process.

The following fundamentals should be considered and applied to all food service facilities, including restaurants, within the constraints of the particular facility and its location, equipment, and systems.

Principles

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

- The building should always be slightly positively pressurized (e.g. +1.25 Pa) compared to atmosphere to prevent infiltration of outdoor air. Infiltrated air contains contaminants and insects, and adds to the heat load.
- Every kitchen should always be slightly negatively pressurized (–0.25 Pa) to adjacent rooms or areas immediately surrounding it to help contain odors in the kitchen and to prevent odor migration out of the kitchen.
- System HVAC design should prevent air supplied to the kitchen from being returned and supplied to non-kitchen areas. Odor contamination is an obvious potential problem. In addition, in conditions such as seasonal transitions, when adjacent zones may be in different modes (e.g., economizer versus air conditioning or heating), comfort may be adversely affected. Ideally, the kitchen HVAC system should be separate from all other zones' HVAC systems. Three situations to consider are the following:
    - During seasonal transitions, the kitchen zone may require air conditioning or may be served by ventilation air only, while dining areas require heating. Even in kitchens that require cooling when the adjacent dining areas require heating, it is still important to maintain the pressure differential between these spaces and continue transfer of dining-area air into the kitchen.
    - To limit kitchen personnel discomfort, it is important to control the low-temperature MUA set point and prevent drastic temperature variations between the kitchen space and MUA being introduced. If dedicated kitchen MUA requires heating, thermostatic control of the MUA heating source should ideally be based on kitchen space temperature rather than outdoor air temperature. MUA heating should be interlocked with kitchen HVAC cooling to prevent simultaneous heating and cooling. Location of HVAC thermostats in kitchens must account for the potential conflicting temperatures.
    - Ideally, will should be no perceptible drafts in dining areas, and temperature variations of no more than 0.6 K. Kitchens might not be draft free; however, velocities at or near exhaust hoods should be no greater than 0.4 m/s. Kitchen comfort is greatly impacted by radiant heat in work areas, but it is desirable to maintain sensible temperatures within 3 K of design conditions. 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, dining customers will be uncomfortable and facility personnel are generally less comfortable and less productive.

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 food service ventilation.

In restaurants with multiple exhaust hoods, or hoods with demand control systems, exhaust airflow volume may vary throughout the day. Replacement air must be controlled to maintain proper building and kitchen differential pressures to ensure the kitchen remains negative to adjacent areas at all operating points. The more variable the exhaust, or the smaller and more numerous 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 include 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. Such spaces that include direct-vent appliances, such as gas-fired water heaters, must maintain the pressure required for safe appliance operation.

Design Best Practices

Life-Cycle Cost Analysis (LCC). As with any engineering design, many considerations must be taken into account to ensure the CKV system operates properly and with the best interest of end users in mind. Life-cycle cost analysis compares the real cost of owning and operating two or more systems over a given period of time (typically 10 to 20 years). For each system, the total life-cycle cost can be calculated using Equation (1) (Fuller and Peterson 1996):

$$\mathrm{LCC} = I + \mathrm{Repl} - \mathrm{Res} + E + W + \mathrm{OM\&R} \quad (1)$$

where

LCC	=	Total LCC in present-value dollars of given alternative
I	=	Present-value investment costs
Repl	=	Present-value replacement costs
Res	=	Present-value residual (scrap) costs
E	=	Present-value energy costs
W	=	Present-value water costs

OM&R = Present-value, nonfuel, operating, maintenance and repair costs

For the kitchen ventilation systems covered in this chapter, the lifetime is typically longer than 10 years; if 10 years is used as the span of the analysis, the replacement costs and scrap costs are zero. For ventilation systems, energy costs could include items such as hood lights, exhaust fans, and the associated HVAC energy to condition supply air; water costs could include heating hot water (if applicable) used for hoods with wash or mist systems; OM&R could include maintenance items, the costs to remove and clean the primary grease extractors in the hood, and periodic replacement of filters in pollution control systems.

For CKV systems, the analysis is typically a comparison of the first cost of the equipment to the operating costs. For CKV systems, the primary operating costs are for conditioning the outdoor air used as replacement air for the kitchen hood exhaust. As such, different climates may yield different LCA values for identical designs.

It is recommended that LCAs be performed on the following items:

- Hoods, including size, type, and options (e.g., increased overhangs and side panels); in some instances, even different manufacturers may yield different results.
- Exhaust fans.
- Makeup air/replacement air designs (comparing untempered to tempered makeup air).
- Cooking effluent reduction technologies to duct cleaning costs.

An example of LCA for a kitchen is selecting the exhaust fan. Table 1 lists several fans that can perform the required, duty. If first cost is considered, the physically smallest (fan A) is the best choice. However, when applying an LCA, the larger fan C is the best option.

Incorporating Variable-Frequency Drives (VFDs) for Exhaust Fan Control

Many kitchen exhaust fans, especially those that are part of a DCKV system, use VFDs to control their speed. If applicable, the VFD will be supplied by the DCKV system supplier, and it should be installed adjacent to the exhaust hood it serves. If the building in which it is installed has the exhaust fans located a considerable distance away, as in tall buildings, the following must be taken into consideration:

- VFDs should have a separate conduit from the VFD to motor. In some cases, VFD output circuits may share conduit for short distances (e.g., in a cable tray, through a roof penetration), for up to 4.6 m.
- If VFD output circuits share conduit for more than 4.6 m, then output reactors should be installed on every VFD.
- No more than two VFD output circuits should share a single conduit for more than 4.6 m.
- Longer VFD-to-motor distances increase the probability that the motor will see higher voltage spikes, which can lead to the motor burning up. The issue gets worse with higher voltages. Methods to address this issue include the following:
    - Specify an inverter-duty motor rated for 1600 V P-P is critical (NEMA *Standard* MG1.1 Part 31)
    - Use a lower switching frequency. This can cause more audible noise at the motor, but is easier on the hardware.
    - Use an output reactor, mounted close to the VFD, to help absorb spikes and reduce reflected wave phenomena on load side of VFD.
    - An output filter, mounted close to the VFD, can also be used, but not in conjunction with output reactors. This provides additional protection to the motor with longer modulated wiring distances.
    - Input reactors, mounted close to the VFD, help smooth out power going to the line side of the VFD and help with rough output voltage on the load side.
- If possible, locate the VFD closer to the motor to reduce the modulated power run from the VFD to the serving motor.
- For retrofit projects, replace existing motors to prevent motor burnout. If existing motor are to be reused, use the following recommended limitations on distance from VFD to motor. Be reasonably conservative, but remember the risk of motor failure always exists.
    - 230 V AC motors: up to 60 m from VFD to motor
    - 460 V AC motors: up to 20 m from VFD to motor

    - 575 V AC motors: up to 12 m from VFD to motor
    - If VFD-to-motor wiring distances exceed these limits, then output reactors are recommended
- For new construction and retrofit projects where the motor is replaced, consider the following limitations on distance from VFD to motor:
    - New motors should comply with NEMA *Standard* MG1 Part 31, which states that the motor winding insulation must be able to withstand voltage spikes of 1600 V peak-to-peak in 0.1 μs.
    - Totally enclosed fan-cooled (TEFC) motors should be used if they fit in the housing of the existing fan.
    - Open dripproof (ODP) motors may be used where TEFC motors do not fit.
    - Where the nominal AC voltage is 575 V (e.g., Canada), new motors must have insulation able to withstand 1700 V p-p.
    - Limitations on VFD-to-motor distance when the motor is new and known to meet the standards of NEMA *Standard* MG-1 Part 31 are
        - 230 V AC motors: up to 152 m from VFD to motor
        - 460 V AC motors: up to 60 m from VFD to motor
        - 575 V AC motors: up to 30 m from VFD to motor
        - If VFD-to-motor wiring distance exceeds these limits, then output reactors are recommended

Dedicated Fan Versus Manifold Exhaust Systems. Whether to connect each exhaust hood to its own dedicated exhaust fan is typically dictated by the physical constraints of the building into which the CKV system is being installed. The duct shaft space needed to install multiple exhaust ducts is not permitted on most projects, especially for any multistory building. Additionally, installing multiple exhaust ducts increases the first cost. Thus, many designs use **manifold exhaust systems**, which consist of multiple exhaust hoods served by a single exhaust fan.

The primary advantage of using a manifold exhaust system is first cost. Less ductwork is needed, which also reduces the amount of floor area lost to duct riser shafts. Additionally, fewer exhaust fans are needed, reducing the costs of equipment as well as associated electrical power wiring.

Table 1 Size, First Cost, and Operating Cost of Five Upblast Exhaust Fans Operating at Same Design Duty

Design Duty: Belt Drive Upblast Fan: 1888 L/s at 373.2 Pa				
Belt Drive Upblast Fan	**Wheel Diameter, mm**	**Relative Cost**	**Est. Cost**	**Operating Cost/Yr, $**
A	469.9	1	$750	$1082
B	542.925	1.09	$818	$1106
C	622.3	1.23	$923	$1023
D	565.15	2.09	$1568	$995
E	685.8	2.81	$2108	$937

The primary disadvantage of manifolded exhaust systems is the challenge of accurately controlling exhaust airflow at each individual hood. Due to fire codes, air-balancing dampers can only be installed as part of the hood collar, and they must be specifically listed for their intended application. Additionally, if a DCKV system is incorporated, the exhaust airflow can only be reduced when either (1) all cooking equipment under all hoods goes into part-load operation, or (2) specialized control dampers listed for installation and operation in cooking exhaust systems are installed along with the necessary controls to integrate with the DCKV system. These details should be considered when performing a life-cycle cost analysis of a manifolded exhaust system. An additional disadvantage is that, should the fan fail, the entire cooking operation loses function.

Table 2 Life-Cycle Analysis of Five Different Exhaust Fans Operating at Same Design Duty*

Belt Drive Upblast Fan	Wheel Diameter, mm	Cost of Ownership for Years 0 to 10										
		0	1	2	3	4	5	6	7	8	9	10
A	469.9	$750	$1,832	$2,915	$3,997	$5,079	$6,161	$7,244	$8,326	$9,408	$10,490	$11,573
B	543.6	$818	$1,923	$3,029	$4,135	$5,241	$6,347	$7,453	$8,559	$9,665	$10,770	$11,876
C	622.3	$923	$1,945	$2,968	$3,990	$5,013	$6,036	$7,058	$8,081	$9,104	$10,126	$11,149
D	566.4	$1,568	$2,562	$3,557	$4,551	$5,546	$6,540	$7,535	$8,529	$9,524	$10,518	$11,513

E	685.8	$2,108	$3,045	$3,982	$4,919	$5,856	$6,793	$7,730	$8,667	$9,605	$10,542	$11,479

* Energy costs = $0.03/MJ; operating 18 h/day and 7 days/week.

For dedicated fan-to-hood systems, first costs are indeed greater for the extra ducts and fans. But the advantages include being able to control exhaust air for each hood simply by changing fan speed. This approach works for both initial balancing and for DCKV control. If a cooking appliance is not being used, the associated fan can be shut off instead of operating at reduced airflow. Finally, should a fan fail, the entire cooking operation will not have to cease.

Multiple-Hood Systems Served by Single Exhaust Fan

Single kitchen exhaust duct/fan systems serving multiple hoods (i.e., manifold exhaust systems) present unique design and balancing challenges. Air balance is one of the main challenges. These systems may be designed with bleed ducts and/or balancing dampers to facilitate balancing the air draw of individual hoods. The dampers can be of blade types that can be set in position manually or operated automatically by a programmable actuator. Balancing dampers must be listed for use with kitchen hoods. Additionally, hood filters are sized to allow pressure loss equalization along the hood for hood containment and capture (C&C). Some filters are adjustable, but should not be used when they can be interchanged between hoods or within the same hood, because such interchange can alter the commissioned air balance of the hoods and exhaust fan. Balancing can also be accomplished by changing the number and/or size of filters.

DCKV in single or manifold applications can automatically provide real-time balancing by using an engineered system listed for use with commercial kitchen hoods, such as one or more of the following: cooking activity sensors, variable-speed exhaust and supply fans, and volume-balancing dampers to modulate hood exhaust. However, the ductwork still must be properly designed to allow each hood to achieve design airflows during full-load cooking operations. When physical space allows, it is good practice to use a separate exhaust fan for each hood. This effectively provides system redundancy and less complexity when balancing.

Exhaust for solid-fuel cooking equipment should be separate from all other exhaust systems. Light-duty smokers, flavoring equipment, or fireboxes that use solid fuel can be installed under the hood serving other cooking equipment, subject to restrictions under NFPA *Standard* 96 and building codes, including size, fuel load and storage, open flame design, and ash removal and disposal.

In some multitenant installations, the duct design may be completed and installed before the tenants have been identified. 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 the system will not achieve proper balance.

For greatest success with multiple-hood exhaust systems, minimize pressure losses in 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 have a smaller effect on total pressure loss and thus on actual airflow.

Minimum code-required air velocity (2.5 m/s) 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 outdoor air, preferably untempered, through a bleed duct system directly into the exhaust duct (Figure 1). 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 also shown in NFPA *Standard* 96 and should be discussed with the authority having jurisdiction.

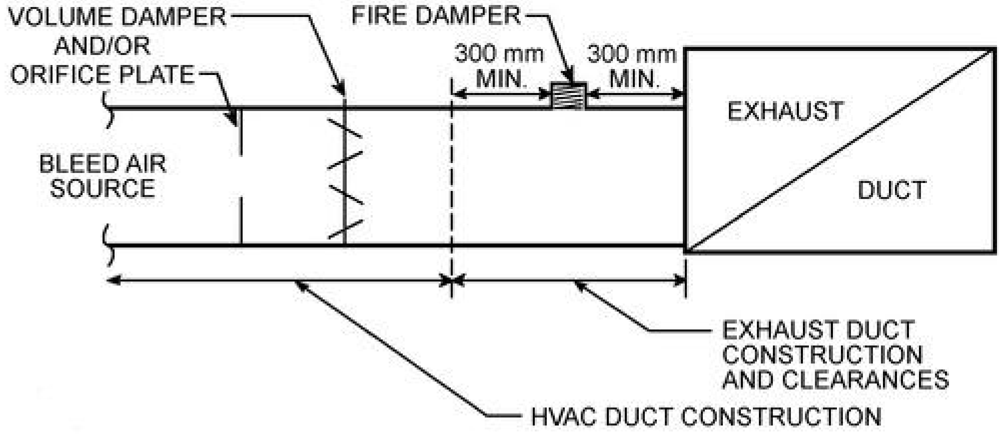


Figure 1. Bleed Method of Introducing Outdoor Air Directly into Exhaust Duct (Brohard et al. 2003)

A fire damper is required in the bleed 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 or as required by the local authority having jurisdiction (AHJ). Means to adjust the bleed airflow must be provided upstream of the fire damper. All dampers must be in the clean bleed air duct so they are not exposed to grease-laden exhaust air. The difference in pressure between bleed 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

Minimum exhaust flow rates for kitchen hoods are determined either by laboratory tests or by building code requirements. Energy codes specify maximum airflow rates. In either case, the installed system must ensure proper capture and containment under maximum cooking load conditions. The majority of kitchen exhaust systems use fixed-speed fans, which move the same volume of air at a given speed regardless of air density. Although the air volume remains constant, heat and moisture generated by the cooking process affect mass flow.

Exhaust fans for kitchen ventilation systems, like for other high-temperature exhaust processes, must be selected to provide adequate airflow at standard conditions to meet the mass flow needs of the actual cooking process. Testing for hood listing in accordance with UL *Standard* 710, for example, requires capture and containment testing using actual cooking, with cooking appliance heated to controlled surface temperatures and food product cooked, including flare-ups, to determine airflow. This airflow must be converted to standard air conditions to provide proper design ratings for fan selections.

1.4 ENERGY CONSIDERATIONS

Restaurants and commercial kitchens are the largest consumers of energy per unit of floor area when compared to other commercial or institutional occupancies (Itron and California Energy Commission 2006). Primary drivers of commercial kitchen energy use are the cooking appliances and the HVAC system. Often, the largest energy-consuming component in a commercial food service facility is the kitchen exhaust. However, energy consumption associated with commercial kitchen ventilation (CKV) and HVAC systems, as well the conservation potential, can vary significantly (Fisher 2003). Beyond the design exhaust ventilation rate itself, the magnitude of energy consumption and cost of a CKV system is affected by factors such as geographic location (i.e., climate), system operating hours, static pressure and fan efficiencies, replacement air heating and cooling set points and level of dehumidification, efficiency of heating and cooling systems, level of interaction between kitchen and building HVAC system, appliances under the hood and associated radiant heat gain to space, and applied utility rates. Minimizing the exhaust airflow needed for cooking appliances and reducing radiant load from the appliances are primary considerations in optimizing CKV system design. Because climatic zones vary dramatically in temperature and humidity, energy-efficient designs have widely varying rates of returns on the investment. In new facilities, the designer can select conservation measures suitable for the climatic zone and the HVAC system to maximize the economic benefits.

The operating cost burden has stimulated energy efficiency design concepts and operating strategies discussed in this section and detailed in industry design guidelines (PG&E 2004). It has also impacted changes to ASHRAE *Standard* 90.1.

The Kitchen Exhaust Systems section of ASHRAE *Standard* 90.1 states that if a CKV system has a total exhaust airflow rate greater than 2.4 m^3/s, the design must adhere to maximum exhaust rates specified for the different hood types. These rates apply to listed hoods, and are set 30% below the minimum values for unlisted hoods dictated by the *International Mechanical Code®* (IMC) (ICC 2018). If a kitchen or dining facility has a total kitchen hood exhaust airflow rate greater than 2.4 m^3/s, it must have one of the following:

- At least 50% of all replacement air is transfer air that would otherwise be exhausted
- Demand ventilation system(s) on at least 75% of the exhaust air, capable of at least 50% reduction in exhaust and replacement air system airflow rates, including controls necessary to modulate airflow in response to appliance operation and to maintain full capture and containment of smoke, effluent, and combustion products during cooking and idle
- Listed energy recovery devices with a sensible heat recovery effectiveness of not less than 40% on at least 50% of the total exhaust airflow

Energy Conservation Strategies

Specifying Exhaust Hoods for Minimal Airflow. The type and style of exhaust hood selected depends on factors such as restaurant type, restaurant menu, and food service equipment installed, as well as flexibility for future kitchen upgrades. Exhaust flow rates are largely determined by the food service equipment and hood style. Wall-mounted canopy hoods function effectively at lower exhaust flow rates than single-island hoods. Single- and double-island canopy hoods are more sensitive to replacement air supply and cross drafts than wall mounted canopy hoods (Swierczyna et al. 2010). Engineered back shelf (proximity) hoods may exhibit the lowest capture and containment flow rates. In some cases, a back shelf hood performs the same job as a wall-mounted canopy hood at one-third the exhaust rate. Cooking appliance type and duty rating must be included in the specification process, because not all hoods (particularly back shelf hoods) are rated or designed for all cooking appliance types or duty ratings.

Threshold exhaust rates for a specific hood and appliance configuration may be determined by laboratory testing under the specifications of ASTM *Standard* F1704-17. Similar in concept to the listed airflow rates derived from UL *Standard* 710, the threshold of containment and capture (C&C) for an ASTM *Standard* F1704 test is established under ideal laboratory conditions and is only a reference point for specifying the exhaust airflow rate for a CKV system.

Side Panels and Overhang. In many cases, side (or end) panels allow a reduced exhaust rate because they direct replacement airflow to the front of the hood and cooking equipment. They are a relatively inexpensive way to improve capture and containment and reduce the total exhaust rate. It is important to know that partial side panels can provide almost the same benefit as full panels. Although tending to defy its definition as an "island" canopy, end panels can improve the performance of a double- or single-island canopy hood. A significant benefit of end panels, when hoods are exposed to cross drafts, is mitigation of the negative effect those drafts have on hood performance. However, air distribution designs that eliminate cross drafts are preferred. Increasing overhang is another specification detail that can improve the hood's ability to capture and allow reduced exhaust rates. It is important that the engineer and food service designers work closely on appliance placement size and type, because they affect hood sizing, which in turn affects lighting, HVAC, and most importantly hood performance. A hood that is too small (i.e., little or no overhang) may often not be capable of working properly at any airflow rate, whereas those with generous overhang may operate well at airflow rates reduced by 30% or more.

Custom-Designed Hoods. Hoods can be custom designed for specific cooking appliances or cooking processes. Customization often reduces exhaust and replacement air quantities and consequently reduces fan sizes, energy use, and energy costs. To operate at flow rates lower than required by code, custom-designed hoods must be either listed or approved by the local code official. The cost involved with custom design makes the process more applicable to chain restaurants, such as quick service, where a specific design may be installed repeatedly. Some single-site establishments may have architectural restrictions that demand a custom solution.

Transfer Air. ASHRAE *Standard* 62.1 specifies the quantity of outdoor air that must be provided to ventilate public spaces, such as dining rooms, in food service establishments. *Standard* 62.1 allows this ventilation air to be reused by transfer from the ventilated public spaces to the kitchen, where it can be used to replace air exhausted by the hood system and assist kitchen comfort. Transfer air must meet the requirements as prescribed in ASHRAE *Standard* 62.1 (section 5.16.3). By maximizing transfer of air from adjoining public spaces to the kitchen, the designer is able to minimize the quantity of dedicated outdoor air supplied to the kitchen as replacement air. This can reduce the energy load on the replacement air system, as well as improve thermal comfort in the kitchen. Most quick-service and fast-casual restaurants do not physically segregate the kitchen from the dining room, so conditioned air can be easily transferred from the dining area to the kitchen. In restaurants where the kitchen and dining room are physically segregated, ducts between the two areas may be required for proper flow of replacement air into the kitchen. Transfer fans may be required to overcome duct losses, because the differential pressure between spaces may be very low (<1.25 Pa). This design can reduce kitchen replacement air requirements and enhance employee comfort, especially if the kitchen is not air conditioned. Codes may restrict transfer of air from adjoining spaces, other than public dining areas, in buildings such as hospitals. Adjoining spaces should not be overventilated to increase transfer airflow, because the heating and cooling conditions for dining and other public spaces are more energy-intense than for conditioning replacement air introduced directly into the kitchen.

Demand-Controlled Kitchen Ventilation

Demand-controlled kitchen ventilation (DCKV) refers to any engineered, automated method of modulating (e.g., variable reduction) the amount of air exhausted for a specific cooking operation in response to a part-load or no-load condition (e.g., by duct temperature, opacity, or appliance surface temperatures).

A DCKV system is different from a DCV system in that the controlling demand factor is the kitchen's cooking operations and not space carbon dioxide (CO_2) levels. In conjunction with this, the amount of replacement air (consisting of makeup, transfer, and outdoor air) is also modulated to maintain the same relative air ratios, airflow patterns, and pressurizations. Failure to integrate systems could cause negative pressure.

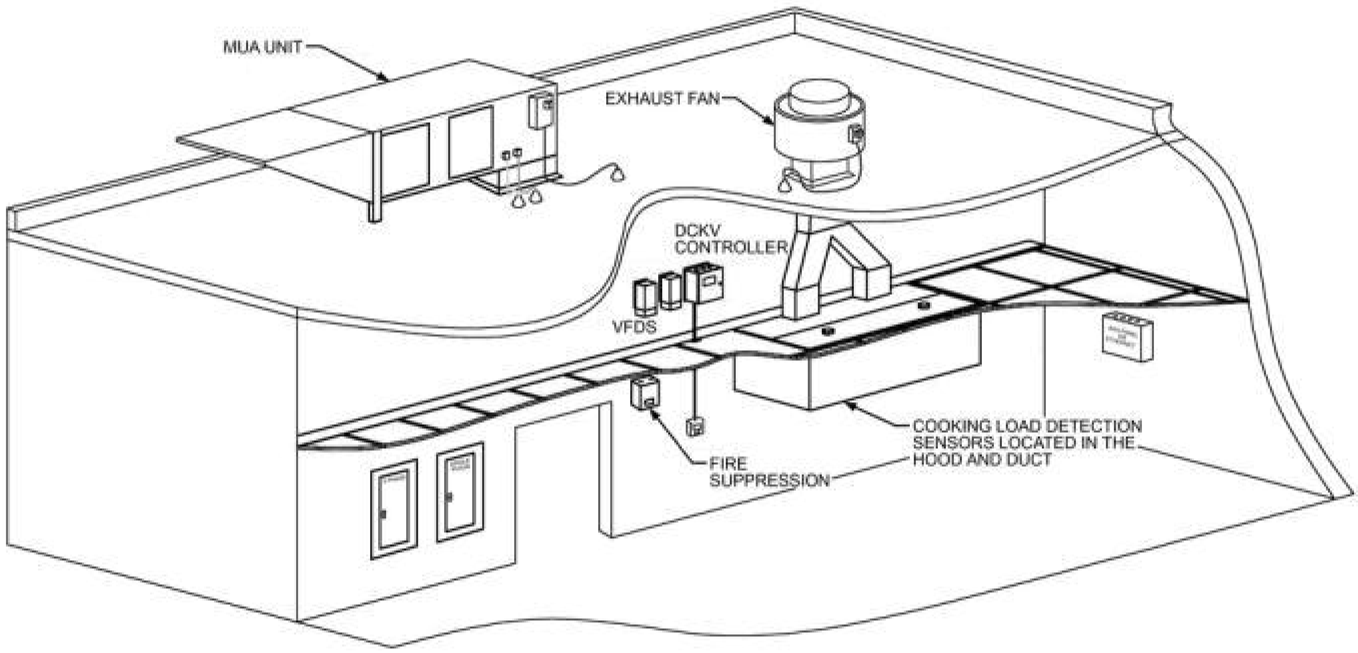


Figure 2. Typical DCKV Equipment and Configuration

The design of all involved ventilation systems must account for DCKV, to create a fully integrated system.

Complete capture and containment of all smoke and greasy vapor must be maintained when a DCKV exhaust system operates at less than 100% of design airflow.

Selection of all components, and design of the DCKV system, must be such that stable operation can be maintained at all modulated and full-flow conditions.

When DCKV is used as the method of compliance with ASHRAE *Standard* 90.1 (section 6.5.7.1.4 part b), it must meet all requirements of that section.

When DCKV is used as the method of compliance with ASHRAE *Standard* 62.1 it must meet the minimum exhaust air rates per Table 6.5 and minimum ventilation air rates per Table 6.2.2.1, ensuring ventilation during periods of occupancy.

The exhaust system configuration and equipment to be served by a DCKV system must be evaluated to determine the feasibility and cost benefits resulting from its use. An example of a situation where a DCKV system may not be appropriate is when gas-underfired broilers are present.

Evaporative Cooling. Direct evaporative coolers are an alternative to mechanical cooling (or, for that matter, no cooling) of replacement air only in dry climates where dehumidification is not required. Indirect evaporative cooling has a wider range in geographical applications. Water costs, availability, and use restrictions should be considered.

Heat Recovery from Exhaust Hood Ventilation Air. High-temperature effluent, often in excess of 200°C, from the cooking equipment mixes with replacement room air, resulting in exhaust air temperatures well over 35°C. It is frequently assumed that this heated exhaust air is suitable for heat recovery; however, over time, smoke and grease in the exhaust air can foul the heat transfer surfaces. Under these conditions, the heat exchangers require regular maintenance (e.g., automatic washdown) to maintain heat recovery effectiveness and mitigate risk of fire. Because heat recovery systems are expensive, food service facilities with large ventilation rates and relatively light-duty cooking equipment are the best candidates for this equipment. Hospitals are a good example, with large exhaust rates and very low levels of grease production from the cooking equipment. An exhaust hood equipped with heat recovery is more likely to be cost-effective where the climate has very cold winters (well below 0°C). A mild climate is not conducive to use of this conservation measure. See Chapter 26 in the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* for more information on air-to-air heat recovery.

Optimized Heating and Cooling Set Points. IMC (ICC 2018) requires that replacement air be conditioned to within 5.6 K of the kitchen space, except when replacement 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 balance points of commercial kitchens. A commercial kitchen may be considered comfortable at temperatures of up to 29°C when space humidity is ≤60%. During heating seasons, space humidity is typically not an issue if the kitchen exhaust systems are properly designed and operated. During the heating season, space gains from unhooded appliances and radiant gains from hooded appliances, lighting, refrigeration units, and staff make it possible to maintain comfort using lower supply air temperatures. During cooling seasons, in climatic areas that require dehumidification, consideration must be given to all sources that may introduce moisture into commercial kitchens, including internal cooking, holding, and washing as well as local makeup air (MUA) systems or kitchen HVAC systems not designed for continuous dehumidification. Humidity control (≤60%) allows optimization of cooling set points at higher temperatures while maintaining a comfortable working environment.

A dedicated outdoor air system (DOAS) providing conditioned outdoor for kitchen heating, cooling, and dehumidification also optimizes set points by using economizer operation when outdoor air alone (no conditioning) can maintain kitchen set points. Using dedicated outdoor air to heat, cool, and dehumidify outdoor air to control space comfort and humidity and replace air exhausted through the hood has been demonstrated to be an energy-effective design for optimizing heating and cooling set points (Brown 2007).

Accordingly, when local MUA systems are used, it is essential that the heating set point of those units not be set higher than the forecasted heating/cooling balance point (e.g., 13°C) to avoid simultaneous replacement air heating and HVAC cooling. It may be more difficult to control comfort when local MUA (e.g., at 13°C) is introduced into a kitchen being heated by a conventional HVAC system introducing kitchen supply air at temperatures ≥27°C.

Reduced Exhaust and Associated Duct Velocities

Tempering outdoor 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 little or no product is being cooked, energy cost can be significantly reduced when combined with a DCKV system. Field evaluations by one large restaurant chain suggest that cooking appliances may operate under no-load conditions for 75% or more of an average business day (Spata and Turgeon 1995).

However, it has been difficult to reduce exhaust flow rates in a retrofit situation because of the minimum duct velocity restriction. National Fire Protection Association (NFPA) *Standard* 96 had historically required a minimum duct velocity of 7.62 m/s. The common belief was that, if 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). The results showed that, for design duct velocities below the traditional 7.5 m/s threshold, grease deposition was not increased; in fact, in isothermal conditions, as duct velocity decreased, grease deposition on all internal sides of the duct also decreased. These results led to NFPA *Standard* 96 and the IMC changing their minimum duct velocity requirements from 7.62 m/s to 2.54 m/s.

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.

The primary benefit of these code-approved duct velocity changes is the potential for reduced food service energy consumption. By reducing excessive exhaust airflows, while maintaining necessary capture and containment, energy for fans as well as for heating, cooling and/or dehumidifying air that was previously wasted may now be saved. Previously, if a restaurant remodeled their cooking operation and the remodel resulted in reduced exhaust airflows, the owner had to install new, smaller-diameter ductwork to comply with the 7.62 m/s duct velocity requirement. This is often too costly, if not also physically impractical. Now, if a system designed for heavy-duty equipment upgrades to more energy-efficient, lighter-duty equipment, exhaust airflows can be reduced without the expense of modifying ductwork.

Reduced code-approved duct velocity also facilitates application of DCKV systems with less resistance from local code authorities. From a new-facility design perspective, it is recommended that most kitchens be designed for an in-duct velocity between 7.62 and 9.1 m/s. This allows for reducing the airflows to 2.5 m/s if needed in the future or as part of a demand-ventilation control strategy.

Due to a higher risk of duct fires associated with solid-fuel cooking equipment, the DCKV application is typically limited to two-speed on/off fan cycles. Dampers, if used for solid fuel, must adhere to the requirement of liquidtight connection and must not downgrade the ductwork. The dampers are mechanically locked in position and must be approved by a fire inspector. NFPA *Standard* 96 requires listed dampers for the application. Duct sizes for solid fuel typically maintain 7.62 m/s duct velocity.

Exhaust from heavy-duty solid fuel cooking can be treated and cooled down by an in-line water mist duct section. The duct system monitors and cycles water mist to maintain a set exhaust temperature threshold. Listed grease ducts have a threshold not exceeding 260°C for continuous exhaust. The design temperature must consider flammability of creosote buildup on duct walls, produced from solid fuel burning as it mixes with cooking vapor from cooking. Creosote and soot mixtures on duct walls can have a lower flash point than grease alone and pose a fire hazard (see the Fire Safety section).

Dishroom Ventilation

Many different types of dishwashing and warewashing equipment are used in the food service industry: powered sink washers; troughs; undercounter, door-type, conveyor-type, and flight-type warewashers; and rack washers. Ancillary equipment such as prerinse valves, scrappers, hoses, and drying dishes are also sources of loads. Each type of equipment operates differently and generates different levels of sensible, latent, and moisture loads to the space. Loads depend on whether the appliance is ventilated, whether sanitization occurs by hot water or chemicals, and the effectiveness of the local ventilation.

Historically, data on heat gains and cooling loads have been scarce. This made it difficult to estimate loads, leading to potentially undersized ventilation and resulting in hot and humid dishrooms with condensation on walls and supply diffusers. ASHRAE research is currently under way to determine heat and moisture loading from these types of equipment. ASHRAE research project RP-1469 (Stoops et al. 2013) found that dishrooms had latent and sensible loads significantly larger than the spaces were designed for, resulting in hot and humid space conditions and the possibility of mold growth.

International Mechanical Code® (ICC 2014), section 507.3, states that: "type II hoods shall be installed above dishwashers and appliances that produce heat or moisture and do not produce grease or smoke as a result of the cooking process, except where the heat and moisture loads from such appliances are incorporated into the HVAC system design or into the design of a separate removal system." The only reliable data for the calculations are listed in Table 5F from Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals*. The internal heat gain calculation is essentially the same for hooded and unhooded appliances. For unhooded dishwashers, the total latent and sensible (convective and radiant) emissions load the space. The designer cannot assume there is no load from low-temperature and heat recovery models. For hooded dishwashers, the emissions are the sensible radiant load. However, if ventilation is inadequate, an appreciable amount of convective load can spill into the space and create hot and humid conditions.

Only limited heat gain values are available from manufacturers. Manufacturers have only recently begun applying ASTM *Standard* F2474 to determine sensible and latent loads from dishwashers. Underwriters Laboratories' new listing and labeling program requires heat recovery dishwashers to list and label the sensible and latent loads during heavy-load operations. Heat gain testing per ASTM *Standard* F2474 is a requirement for heat recovery dishwashers as part of a supplement to UL *Standard* 921.

Industry is beginning to realize the opportunities and benefits of heat recovery in a commercial food service facility. The range of application varies from air-to-water heat exchangers above fryer flues, to grease filters incorporating fin-and-tubes to transfer the high-quality heat to preheat water for the dish machine or water heater or to preheat makeup air. In any case, heat exchanger effectiveness ranges between 18 and 63%. The designer must realize that not all the heat is recovered: some amount of heat (both sensible and latent) is released to the space. In the same way, a recirculating or ductless hood system loads the space with nearly the entire plug load from the hood/appliance system. Heat is emitted to the space from heat recovery kitchen equipment, depending on the effectiveness of the heat exchanger. Table 5F in Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals* lists the residual heat gain for a few dish machine types. However, as designs become more efficient (e.g., heat pump dish machines releasing 20 to 21°C dry-bulb temperatures), there is always an amount of moisture that must be considered along with elevated dry-bulb temperatures.

Designing for High-Performance Green Building Compliance under ANSI/ASHRAE/USGBC/IES *Standard* 189.1

There are several sections in this standard that any CKV system must comply with in order to be considered a high-performance green building.

Air-Side Economizer Controls for Replacement Air (Makeup Air). Given the large quantities of replacement air typically required for a CKV system, the use of air-side economizers should be evaluated for every location. This evaluation should include comparing the CKV system's typical daily hours of operation to the number of hours of free cooling available in the local climate. Some locations in ASHRAE climate zones 1A and 1B may still benefit from using air-side economizers, especially if they operate enough hours of the year that they can take advantage of free cooling.

ENERGY STAR Appliances. Commercial food service appliances (e.g., fryers, hot food holding cabinets, refrigerators and freezers, steam cookers, ice machines, dishwashers, griddles, ovens) should bear the ENERGY STAR label. Equipment selection guidance and specifications can be found at www.energystar.gov/.

DCKV for Airflow Greater than 0.9 m^3/s. Kitchen/dining facilities with total kitchen hood exhaust airflow rates above 0.9 m^3/s must comply with at least one of the following:

- At least 50% of all replacement air must be transfer air that would otherwise be exhausted.

- At least 75% of kitchen hood exhaust air must be controlled by a demand ventilation system(s), which must (1) be able to reduce exhaust and replacement air system airflow rates by no more than the larger of 50% of total design exhaust and replacement air system airflow rate, or the outdoor airflow and exhaust rates required to meet the ventilation and exhaust requirements of Sections 6.2 and 6.5 of ANSI/ASHRAE *Standard* 62.1 for the zone; (2) include controls to modulate airflow in response to appliance operation and to maintain full capture and containment of smoke, effluent, and combustion products during cooking and idle; (3) include controls that result in full flow when the demand ventilation system(s) fail to modulate airflow in response to appliance operation; and (4) allow occupants to temporarily override the system(s) to full flow.
- Listed energy recovery devices with a sensible heat recovery effectiveness of not less than 40% must be applied on at least 50% of the total exhaust airflow.
- In climate zones 1B, 2B, 3B, 4B, 5B, 6B, 7B, and 8B, when replacement air is uncooled or cooled without mechanical cooling, the capacity of any nonmechanical cooling system(s) (e.g., natural or evaporative cooling) must be demonstrated to be no less than the system capacity of a mechanical cooling system(s) necessary to meet the same loads under design conditions.

Outdoor Airflow Measuring. Each mechanical ventilation system shall have a permanently installed device to measure the minimum outdoor airflow rate that meets the following requirements:

- The device must use methods described in ASHRAE *Standard* 111.
- The device's accuracy must be ±10% of the minimum outdoor airflow. Where the minimum outdoor airflow varies, as in demand control ventilation systems, the device must maintain this accuracy over the entire range of occupancy and system operation.
- The device must be able to notify the building operator, either by activating a local indicator or by sending a signal to a building monitoring system, whenever an outdoor air fault condition exists. This notification requires manual reset.
    - **Exception:** Constant-volume air supply systems that do not use demand control ventilation and use an indicator to confirm that the intake damper is open to the position needed to maintain design minimum outdoor airflow do not require notification ability.

Energy Measurement Devices. Energy consumption must be measured by devices to track and record energy profiles so that periodic assessments can be made to assure continued future performance. In addition to whole-building monitoring, submetering may be required on specific appliance lineups depending upon capacity. See section 7 of ANSI/ASHRAE/USGBC/IES *Standard* 189.1 for additional information.

Commissioning. Facilities with a gross floor area over 465 m^2 must be commissioned. Commissioning is essential to ensure that the building, including the kitchen exhaust and HVAC systems, functions as intended. For additional information on high performance building commissioning requirements, see section 10 of ANSI/ASHRAE/USGBC/IES *Standard* 189.1.

1.5 THERMAL COMFORT

Due to the many heating, ventilation, and air conditioning operations that can occur (sometimes simultaneously) in a commercial kitchen, determining parameters for a thermally comfortable environment poses a challenge. ASHRAE research project RP-1469 (Stoops et al. 2013) was executed in response to this dilemma. Data were gathered by surveying kitchen workers in over 100 U.S. restaurants, including casual dining, institutional, and quick-service restaurant dishrooms, in different climates, in both summer and winter. The data points were evaluated to quantify thermal comfort in commercial kitchens (Figure 3).

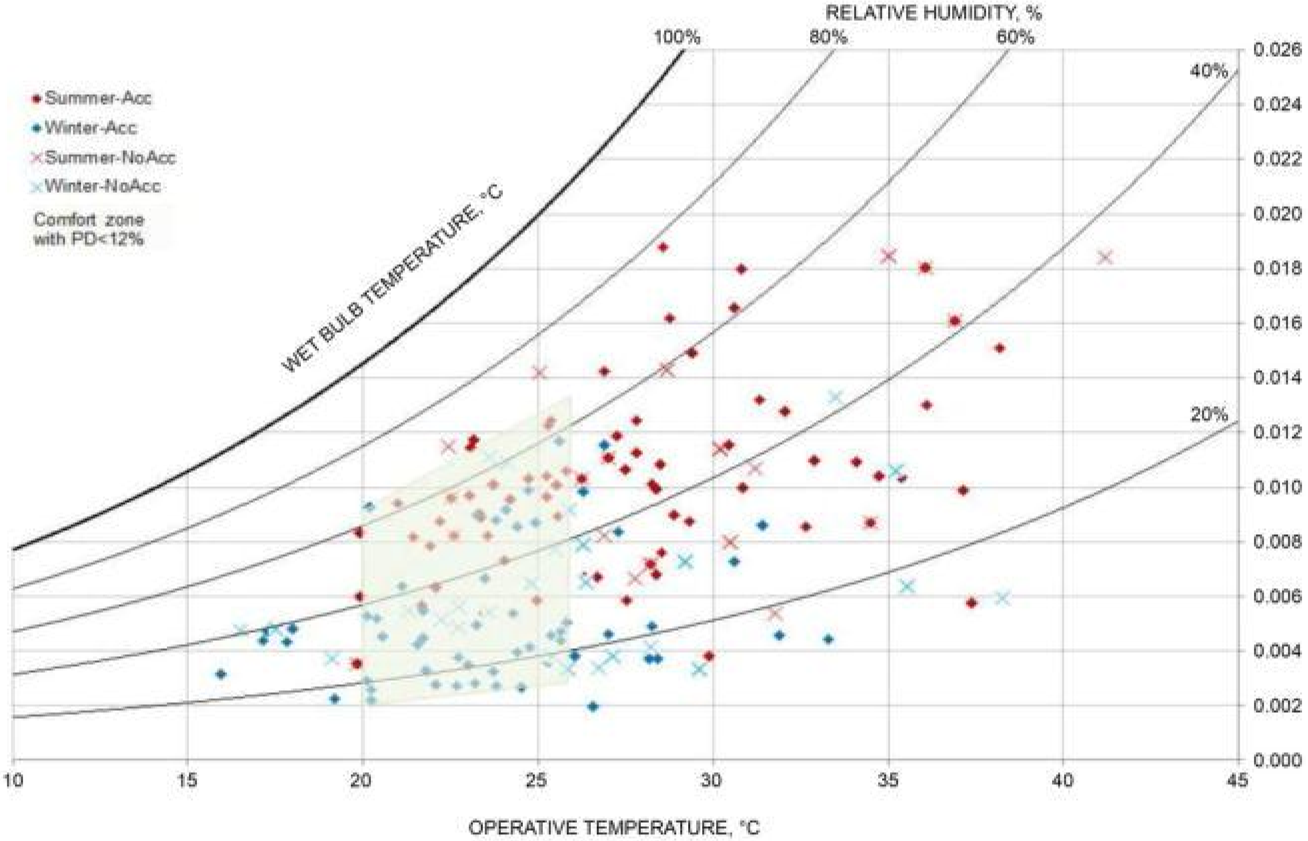


Figure 3. Thermal Comfort Zone for Commercial Kitchens Work Space Based on the Results From RP-1469: Comfort in Commercial Kitchens (Stoops et al. 2013)

The researchers developed a kitchen comfort zone as a region of the psychrometric chart, including a region with a percent dissatisfied PD < 12%. However, nearly 60% of the temperature and humidity data collected in the study were outside the bounds of the comfort zone. The operative temperature was as high as 42°C, and relative humidity was as high as 78%. Such conditions lead to poor working environment, low productivity, bad morale, and mold growth. Based on these results, it is recommended that commercial kitchen design conditions should align with the results shown on the chart, with maximum dry-bulb temperature of 26°C and humidity 60%.

Dishwashing Area

Previously, there was inadequate design data to calculate the internal loads from dishwashing equipment. This resulted in undersized HVAC equipment and poor air distribution, leading to hot and humid kitchens. The findings of RP-1469 determined that the operative temperatures were as high as 29°C and with 71% rh; the correlating average predicted mean vote was above 2 (warm). The long-term measurements found considerable daily temperature variations in the dishwashing area from 24 to 32°C during working hours. If the dishwashing area was open to the cooking line, the thermal radiation from the hot appliance line raised the operative temperature by an additional 5.6 K, it was reported to peak as high as 39°C. The relative humidity in the kitchen space was recorded during the working hours in the three different kitchen zones (i.e., cook line, prep line, and dishwashing area). The relative humidity was up to 55% higher in the dishwashing area than in the other two zones. Long term data at some quick serve restaurants recorded humidity averages up to 69% in the dishwashing area during the summer.

1.6 COMMERCIAL EXHAUST HOODS

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

The type of hood required, or whether a hood is required, is determined by the type and quantity of emissions from cooking. Hoods are not typically required 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 (as mentioned in 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 design of the 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 hoods 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 that produce smoke or grease-laden vapors (e.g., ranges, fryers, griddles, gas underfired and electric broilers, ovens).

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 as authorized by the AHJ.

Type I Hoods

Categories. Type I hoods fall into two categories: unlisted and listed. **Unlisted hoods** are no longer allowed under ASHRAE *Standard* 154. However, if they are used, they must 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 (UL) *Standard* 710 and 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 also distinguish between water-wash and dry hoods.

All listed hoods are subjected to electrical (if applicable), temperature, and cooking smoke and flare-up (capture and containment) tests. A listed exhaust hood with exhaust damper includes a fire-actuated damper, typically at the exhaust duct collar. 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. Also, listed hoods that incorporate an integral supply air plenum include a fire-actuated damper in that plenum; the damper's location in the supply air plenum depends on plenum configuration. Refer to NFPA *Standard* 96 and UL *Standard* 710 for examples of the damper in exhaust hood supply air plenum.

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 as primary grease filter. To date, stand-alone mesh filters have not met the requirements of UL *Standard* 1046, and therefore cannot be used as primary grease filters. For cooking with solid-fuel equipment, embers from wood burning promote duct fires. The grease filters for solid-fuel hoods are supplied with metal screens to protect to some extent against embers entering the exhaust duct. Typically, design practice for heavy-duty solid-fuel cooking equipment evaluates if water mist cooling is required to protect the exhaust system from duct fires.

ASTM *Standard* F2519 provides a test method to determine the grease particle capture efficiency of grease filters and extractors. Grease removal devices generally fall into the following types:

- **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 in accordance with 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 in accordance with UL *Standard* 1046, or may be listed as part of the hood in accordance with UL *Standard* 710. Hoods that are listed with removable extractors cannot have those extractors replaced by other extractors.

- **Stationary extractors** are integral to the listed water-wash exhaust hoods and 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.

- **Water-wash hoods** fall into two classifications: clean-in-place and cold-water mist styles. Clean-in-place hoods reduce or eliminate the need for kitchen staff to manually clean the hood components; these hoods may have fixed stationary or removable grease extractors. These systems may automate the removal of the grease load on the filters, hood plenums, and ductwork. Typical hoods include one or more manifolds with spray nozzles that, when activated, wash out the collected grease with hot, detergent-injected water. The wash cycle is activated periodically, typically after cooking equipment and fans have been turned off. Washdown cycles can lasts 3 to 10 min, depending on the hood manufacturer, type of cooking, duration of operation, water temperature, and pressure. Most water-wash hood manufacturers recommend a water temperature of 54 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 an optional automatic means of activating the water-wash system in the event of a fire.

- Some water-wash hood manufacturers provide continuous cold water mist 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 per 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 cooking equipment, because the water acts as a spark arrestor to satisfy code requirements.

- **Multistage filters** 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 these multistage filters must be tested and certified by a nationally recognized test laboratory in accordance with UL *Standard* 1046.

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

In 2005, however, a new grease filter and extractor test standard was published: ASTM *Standard* F2519, which determines the grease particle capture efficiency of both removable filters and fixed extractors such as those used in 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 ranging from 0.3 to 10 μm that are released into a hood to represent the cooking effluent. The particles are then sampled and counted downstream in the duct with an optical particle counter, with and without the filter or extractor in place. The difference in the counts is used to calculate the particulate capture efficiency graphed versus particle size. ASTM *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 styles for Type I hood applications. These style names are not used 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.
- **Back shelf/proximity,** used for counter-height equipment typically located against a wall, but possibly freestanding.
- **Pass-over,** used over counter-height equipment when pass-over configuration (from cooking side to serving side) is required.
- **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.
- **Eyebrow,** used for direct mounting to ovens and some dishwashers.

Applying Back-Shelf-Style Exhaust Hoods. Due in part to the close proximity of back shelf hoods to the cooking surface, when back shelf hoods are properly applied over appropriate appliances, the exhaust airflow may be reduced to achieve significant energy savings by reducing both exhaust fan motor energy use and makeup air energy. In addition to lower airflows, back shelf hoods can provide health and comfort advantages by exhausting cooking effluent back away from and below the operator’s breathing zone. Close proximity to the appliance also creates the potential for a more open ceiling space, which may be used to locate ceiling lighting fixtures to properly illuminate both the kitchen and appliance work surfaces, as well as providing open ceiling spaces to optimize location of HVAC diffusers.

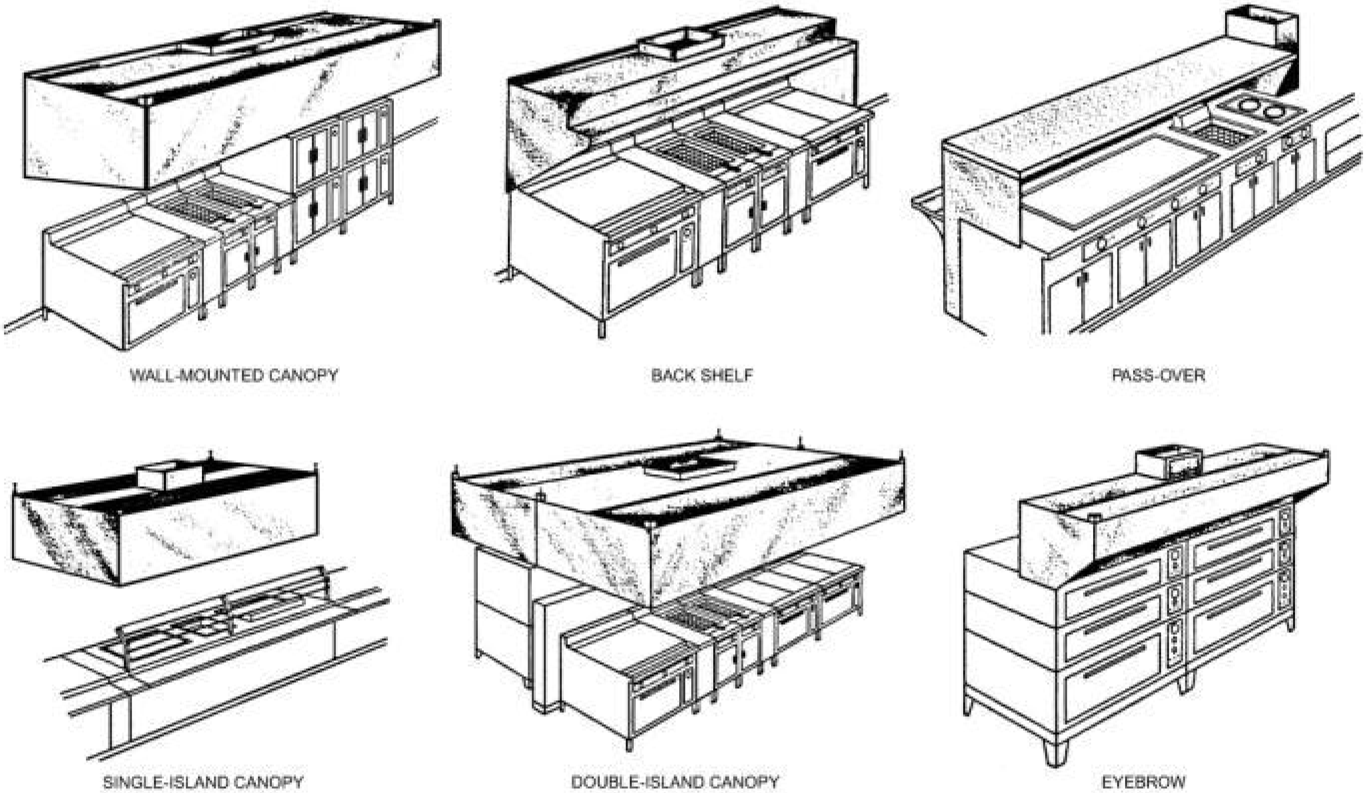


Figure 4. Styles of Commercial Kitchen Exhaust Hoods

Back shelf hoods operate best when located over appropriate appliances, such as those with flat horizontal cooking surfaces, including griddles, under-fired broilers, and deep fat fryers. However, not all appliances can be properly operated when located under a back shelf hood. Examples are upright appliances such as ovens, unless specifically design for such use, and appliances with lids that block effluent from entering the hood, such as tilting fry pans.

It is important to match appliance and hood duty ratings, because maintaining proper capture and containment airflow rates is critical for back shelf hoods. Be mindful of how required setback and side overhang will be impacted by final appliance placement. Consider also the impact of gas lines, electrical connection, and even appliance gas regulators on final appliance location. Sometimes these connection points can cause the appliances to be relocated so that they are no longer properly located under the hood.

These hoods require a more detailed analysis of operation and future menu considerations. Additionally, application of back shelf hoods requires more coordination between specifiers and users to be sure selections support food service operations. Attention should also be paid to the need to enclose or trim the connecting exhaust duct runs in a manner that complies with both fire safety and health regulations.

It is also necessary to confirm that a fixed-pipe fire suppression system can be designed and installed to provide proper fire safety protection for the appliances and the exhaust system. Do not specify back shelf hoods over cooking appliances or cooking operations than cannot be properly protected by an approved fire suppression system.

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 (Swierczyna et al. 2006, 2010) indicates that 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 effluent create thermal air currents that are 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 equipment may require an additional allowance for exhaust of combustion products and combustion air.

Table 3 Appliance Types by Duty Category

Light duty (200°C)	Electric or gas	Ovens (including standard, bake, roasting, revolving, re-therm, convection, combination convection/steamer, conveyor, deck or deck-style pizza, pastry)
		Steam-jacketed kettles
		Compartment steamers (both pressure and atmospheric)
		Cheesemelters
		Re-thermalizers
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	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.	

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 3. Table 4 lists the required hood type by duty level.

Table 4 Type I Hood Requirements[a] by Appliance Type

Appliance Description
Light Duty
Braising pan/tilting skillet, electric
Oven, baking, electric and gas
Rotisserie, electric and gas
Combination, electric and gas
Convection, full-size, electric and gas
Convection, half-size, electric and gas (protein cooking)
Conveyor, electric
Deck, electric and gas
Duck, electric and gas
Revolving rack, electric and gas
Rapid cook, electric
Roasting, electric and gas
Rotisserie, electric and gas
Stone hearth, gas
Range, cook-top, induction

Discrete element, electric (with or without oven)

Salamander, electric and gas

Medium Duty

Braising pan/tilting skillet, gas

Broiler, chain conveyor, electric

Electric, under-fired

Fryer, doughnut, electric and gas

Kettle, electric and gas

Open deep-fat, electric and gas

Pressure, electric and gas

Griddle, double-sided, electric and gas

Flat, electric and gas

Oven, conveyor, gas

Range, open-burner, gas (with or without oven)

Hot top, electric and gas

Smoker, electric and gas

Heavy Duty

Broiler, chain conveyor, gas

Electric and gas, over-fired (upright)

Gas, under-fired

Grill, plancha, electric and gas

Oven, tandoor, gas

Range, wok, gas and electric

Extra-Heavy Duty

Oven, stone hearth, wood-fired or wood for flavoring

Solid-fuel cooking appliances combusting a solid fuel (such as wood, charcoal, or coal) to provide all or part of the heat for the cooking process[b]

Source: ASHRAE *Standard* 154-2016; Table 1.

[a] Where recirculating systems or recirculating hoods are used, the additional heat and moisture loads generated by such appliances should be accounted for in the sensible and latent loads for the HVAC system.

[b] Solid-fuel flavoring cooking appliances should comply with Table 1 as if they do not combust solid fuel.

These categories apply to unlisted and listed Type I hoods. ASHRAE *Standard* 154-2016 requires that all Type I hoods be listed; unlisted hoods are not allowed. The exhaust 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 tests and 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 flowrates for deeper hoods, because the larger reservoirs of deeper hoods typically increase hood capture and containment performance.

Table 5 lists typical exhaust flow rates for listed hoods. 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 use listed hoods. Actual exhaust flow rates for hoods with internal short-circuit replacement air are typically higher than those in Table 5, although net exhaust rates (actual exhaust less internal makeup 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. The exhaust flow rates for listed hoods are established by conducting tests per UL *Standard* 710. Typically, exhaust flow rates are much lower than those dictated by the model codes. Note that listed flow rate 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 710 cover one or more cooking duty ratings: light, medium, heavy, and extra heavy. These duty ratings correspond to minimum cooking surface temperatures during tests of 103, 205, 315, and 370°C respectively. In application, these temperature ratings correspond to duty ratings (see Table 4). The total exhaust flow rate is calculated by multiplying the hood exhaust flow rate by hood length.

ASTM *Standard* F1704 details a laboratory flow visualization procedure for determining the capture and containment threshold of an appliance/hood combination. This procedure can be applied to all hood types and configurations installed over any cooking appliances. ASTM *Standard* F2474 also provides a laboratory test procedure for determining heat gain of specific combinations of exhaust hood, cooking equipment, type of foods, and cooking processes. Results from a series of interlab heat gain tests (Fisher 1998; Swierczyna et al. 2008) have been incorporated in Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals*.

Table 5 Typical Exhaust Flow Rates by Cooking Equipment Category For Listed Type I Hoods

	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	230 to 310	310 to 465	310 to 620	540+
Single-island canopy	390 to 465	465 to 620	465 to 930	850+
Double-island canopy (per side)	230 to 310	310 to 465	390 to 620	775+
Eyebrow	230 to 390	230 to 390	—	—
Back shelf/proximity/pass-over	155 to 310	310 to 465	465 to 620	Not recommended

Island Canopy Hoods

Island canopy hoods, particularly single-island style, have become popular in open cafeteria operations such as those found in university food service. In many cases, the food service consultant specifies gas underfired broilers and other heavy-duty cooking equipment as part of the design. For a given line of appliances, a single-island canopy hood requires significantly more exhaust than a wall-mounted canopy hood. Single-island canopy hoods present the most difficult capture and containment challenge in hood applications, and are often the source of the "hood" problem in a kitchen with display cooking. To address the lack of reliable performance data on island canopy hoods, ASHRAE research project RP-1480 (Swierczyna et al. 2010) was undertaken to determine appropriate exhaust airflow rates. The objective was to expand the database for the exhaust rates required for capture and containment of standardized cook lines under four island canopy hood configurations: rear filter single island, V-bank single island, and 2.4 m deep and 3 m deep double-island hoods. Four side panel designs, four supply air strategies, and two makeup air temperature set points were also evaluated to quantify the effects of these features on island hood performance.

Swierczyna et al. (2010) confirmed that single-island canopy hoods need significantly higher exhaust airflow rates than their wall-mounted counterparts to effectively ventilate cooking equipment for a given duty class. For example, although an exhaust rate of 460 to 620 (L·s)/m can be adequate for complete capture and containment with a wall-mounted canopy hood over a heavy-duty appliance line (ASHRAE *Standard* 154; PG&E 2010), a single-island canopy hood may require an exhaust rate in excess of 770 (L·s)/m in many situations (measured along one side of the canopy hood). In fact, there were several test scenarios for single-island hoods where an exhaust rate in excess of 1080 (L·s)/m was required to achieve capture and containment. This contradicts common design practice, where the specified ventilation rates are often much closer to those for wall-canopy hoods.

Single-island hood performance was improved by the larger hood's V-bank filter configuration over the smaller hood's rear filter configuration for most test configurations. The plume was better aligned with the filters and was drawn toward the center, relative to the front and rear of the hood. The larger V-bank hood was found to be less sensitive to local air replacement. However, aggressive appliance plumes that focused on the flat bottom of the V-bank, or replacement air strategies that were focused at the side of the V-bank, proved challenging and indicated that a change of filter bank profile may improve hood performance.

The performance of a double-island canopy hood, with balanced replacement air, can be comparable to back-to-back wall-mounted canopy hoods for a given duty class of appliances. For example, a heavy-duty front line and a light-duty back line under the double-island hood required an exhaust airflow rate approximately 470 L/(s·m) (measured along both sides of the hood). This rate is comparable to the ventilation rate for similar appliance duty classes under wall-mounted canopy hoods (Swierczyna et al. 2006). The double-island hood configuration performed as if a wall existed between them. Furthermore, the back-to-back appliance lines created a converging thermal plume that helped direct the plume toward the filter bank. However, without a wall between them, the double-island hood system was more susceptible to cross drafts than a wall-mounted hood configuration.

The configuration, volume, and temperature of makeup air was critical to the performance of the double-island canopy hood. Consistent with previous research (Brohard et al. 2003), reducing local makeup airflow rates and velocities corresponded with reduced capture and containment exhaust rates, in most cases. When air volume and associated velocity and turbulence near the hood was minimized, the appliance plumes were more stable and the hood was able to capture and contain at a lower exhaust rate. However, when local makeup air was introduced aggressively through four-way diffusers, perforated diffusers, or a high-flow perforated perimeter supply system, hood performance degraded severely. For double-island configurations, a perforated perimeter supply system operated at a low-flow, low-velocity condition was the best of the local makeup air configurations tested. When the perforated perimeter supply system delivered low-flow, low-velocity air adjacent to the hood (i.e., less than 60% of replacement air requirement), hood performance improved significantly over the high-flow, high-velocity introduction (i.e., greater than 60% of replacement air requirement), and in some cases, better than the exhaust-only configuration with displacement supply. Higher replacement air temperatures from ceiling diffusers also degraded the performance of island hoods. Unbalanced replacement air distribution was extremely detrimental to the performance of the double-island hoods.

Other research highlights the advantages of using side panels for wall-mounted canopy hoods and a variety of replacement air conditions (Brohard et al. 2003; Swierczyna et al. 2006). However, results from the double-island canopy hood testing regarding side panels were inconclusive. A more extensive side panel (and center partition) investigation would need a larger laboratory where replacement air was introduced more uniformly around the hood to eliminate the effect of relatively high, directional local velocities.

A partition between the two appliances lines improved performance of a double-island hood when coupled with a balanced supply on both sides of the hood. However, if as little as 470 L/s was exhausted from the side opposite from the supply air delivery, performance of the double-island hood degraded. This was contrary to the expectation that the partition would be more of a benefit with unbalanced replacement air and its ability to mitigate the effect of cross drafts.

Increased hood overhang was shown to be one of the most effective performance enhancements for island canopy hoods. With a heavy-duty three-broiler appliance line centered front-to-rear under the single island hoods, rather than at a minimum prescriptive front overhang dimension, a 14% exhaust reduction was possible for the smaller rear filter hood, and a 40% exhaust reduction was possible for the larger V-bank hood. Likewise, when side overhang was increased to 610 mm from the minimum of 150 mm, a 41% exhaust rate reduction was found for both single-island hoods. However, the results did not show a significant performance difference between the 2.4 m and 3 m deep double-island hoods. Increased side overhang was found to be one of the most effective performance enhancements for double-island canopy hoods. Increasing the side overhang to 610 mm resulted in a 250 L/(s · m) reduction in exhaust flow rate.

Tailored exhaust bias for double-island hoods may improve hood performance. With more exhaust volume focused over the more challenging appliances, the exhaust rate can be reduced for a given configuration. However, application of a specific bias for other applications or hood dimensions may yield different performance results and should be verified.

Specification of enhanced hood edge geometry should be considered by manufacturers and end-users. Although each design needs to be properly evaluated for its effect on hood performance, the design tested in this project was effective and was typical of edge design currently found in the industry.

Performance in the field should be verified to ensure proper hood capture and containment operation. As shown by RP-1480 (Swierczyna et al. 2010), many factors interact in the kitchen and affect hood performance. These interactions cannot be perfectly predicted for each installation. Therefore, a field test is best to verify proper kitchen ventilation and hood performance.

Wall Canopy Hoods, Appliance Positioning, and Diversity

ASHRAE research project RP-1202 (Swierczyna et al. 2006) quantified the effect of the position and/or combination of appliances under a wall canopy exhaust hood on the minimum 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 gas underfired broilers, representing the light, medium, and 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. (2006).

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 6). 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 6 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%.

Appliance position testing confirmed the exhaust rate of an appliance line is 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 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 5.

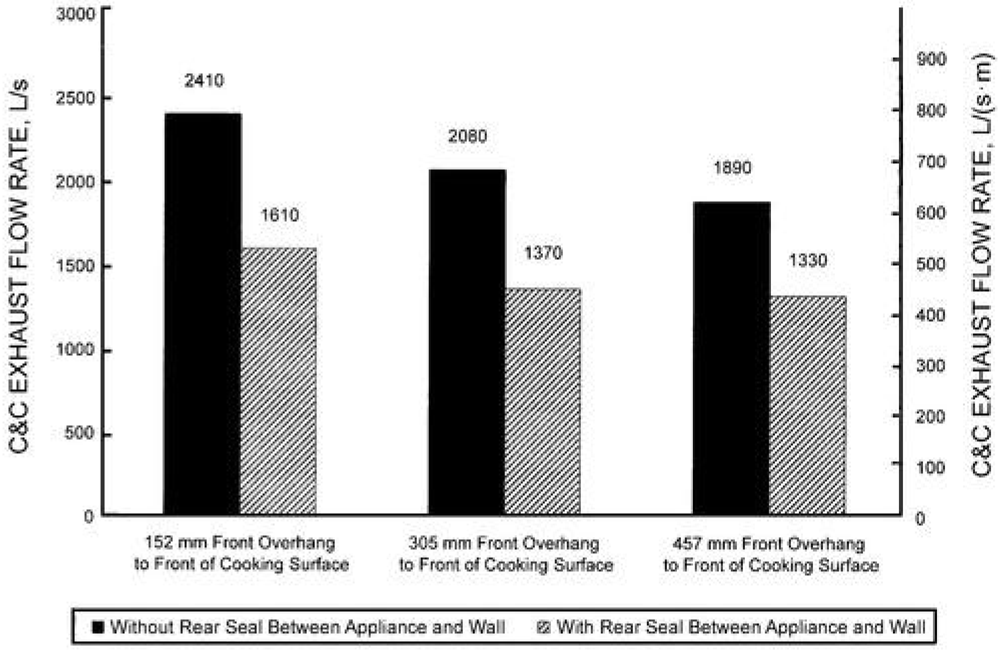


Figure 5. Capture and Containment Exhaust Rates for Gas Underfired Broilers under 3 m Wall Canopy Hood With and Without Rear Appliance Seal at Various Front Overhangs (Swierczyna et al. 2006)

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 6). 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 gas underfired 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 6 also shows that cooking with only the center appliance, with the two end appliances turned off, greatly reduced the exhaust requirement.

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. 2006)

Figure 6. 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. 2006)

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 7).

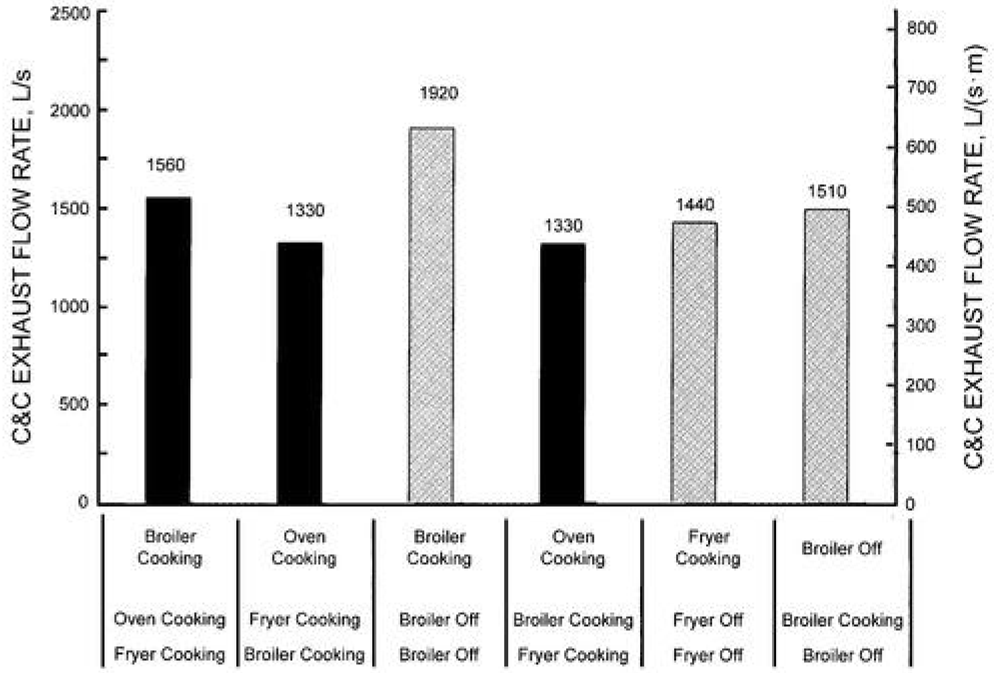


Figure 7. Capture and Containment Exhaust Rates for Cooking Conditions on Multiduty Appliance Lines (Compared with Single-Duty Lines with Only One Appliance Operating) under 3 m Wall Canopy Hood (Swierczyna et al. 2006)

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.

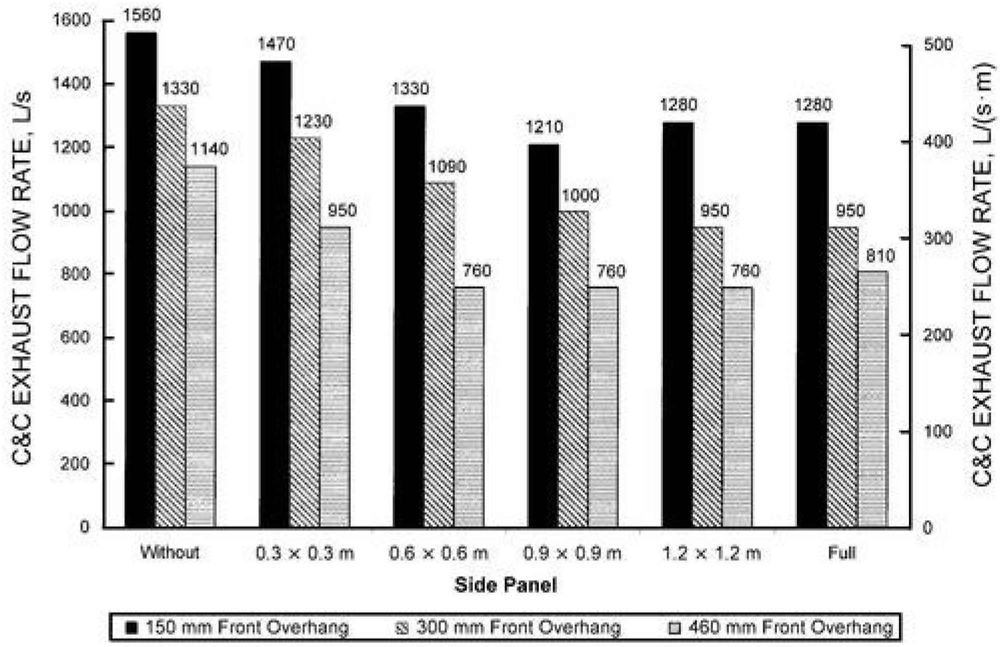


Figure 8. Exhaust Capture and Containment Rates for Three Two-Vat Gas Fryers with Various Side Panel and Overhang Configurations under 3 m Wall Canopy Hood (Swierczyna et al. 2006)

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.

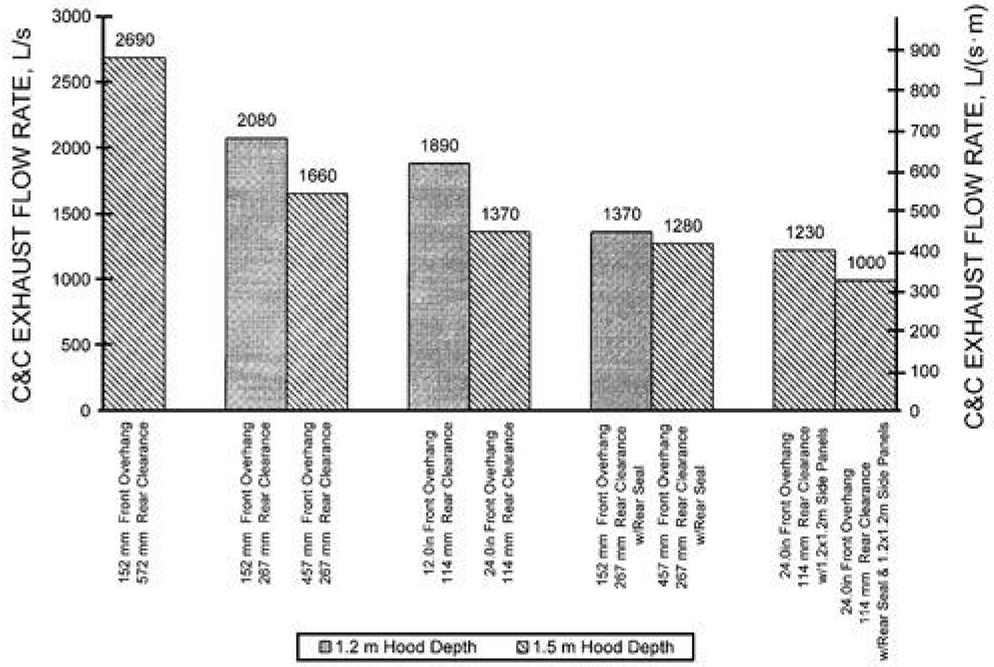


Figure 9. Exhaust Capture and Containment Rates for Heavy-Duty Gas Underfired Broiler Line under 3 m Wall Canopy Hood with 1.2 and 1.5 m Hood Depths and Front Various Front Overhangs (Swierczyna et al. 2006)

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 gas underfired 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 effect 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 underfired 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 exhaust rate was reduced. 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.

Table 6 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

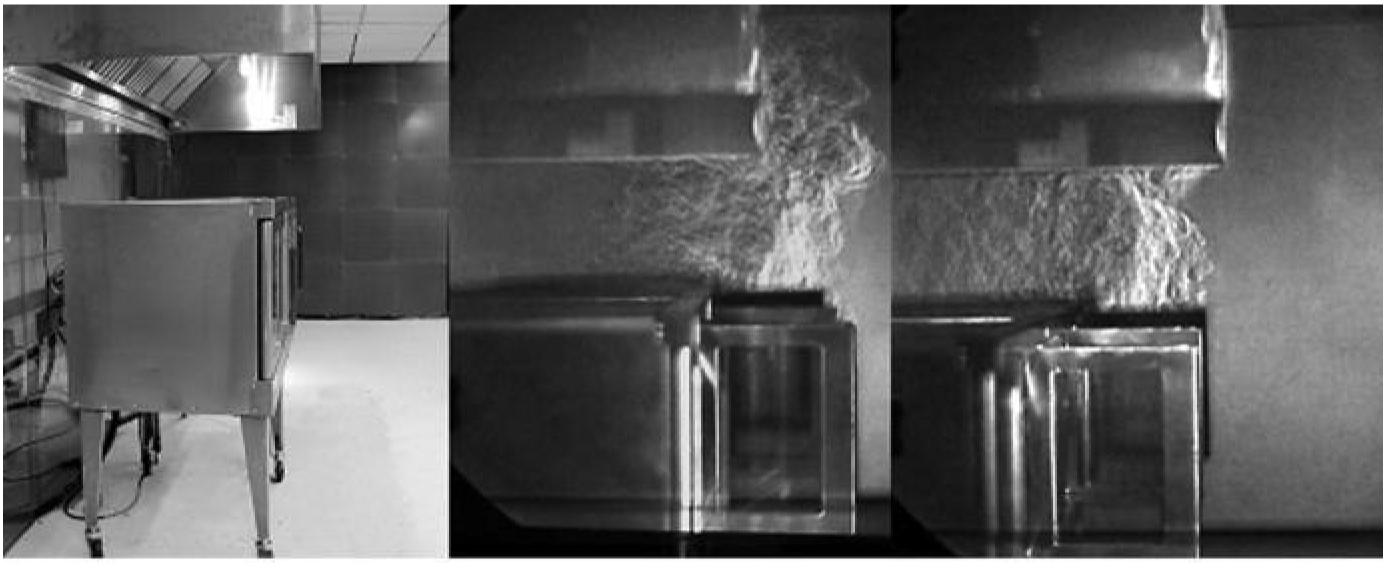
	Best Case	Good Case	Worst Case
Three electric full-sized convection ovens	230 mm front overhang full side panels 130 L/(s · m)	230 mm front overhang 170 L/(s · m)	150 mm front overhang 190 L/(s · m)
Three two-vat gas fryers	460 mm front overhang partial side panels 250 L/(s · m)	460 mm front overhang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

Source: Swierczyna et al. (2006).

* 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]).

Design Guidelines. Swierczyna et al. (2006) 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.
- Introduce replacement air at low velocity. Do not locate four-way diffusers near hood, and minimize use of air curtains.



(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

Figure 10. Three Ovens under Wall-Mounted Canopy Hood at Exhaust Rate of 1600 L/s (Swierczyna et al. 2006)

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.

Table 7 Exhaust Static Pressure Loss of Type I Hoods for Various Exhaust Airflows*

	Hood Static Pressure Loss, Pa			
Type of Grease Removal Device	**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.

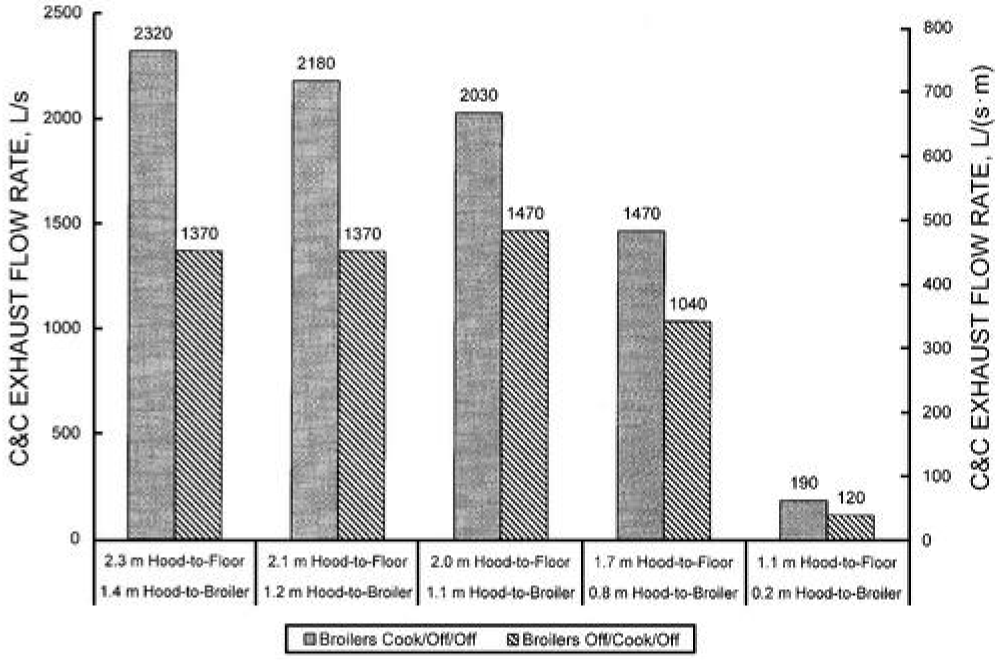


Figure 11. Exhaust Capture and Containment Rates for a Gas Underfired Broiler under 3 m Wall Canopy Hood at Various Mounting Heights (Swierczyna et al. 2006)

Static Pressure. Static pressure drop through hoods depends on the type and design of the hood and grease removal devices, size of duct and duct connections, and flow rate. Table 7 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 ducts 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. Hood material is usually noncorrosive, and filters are usually installed.
- **Heat/fume hood.** For hoods over equipment producing heat and fumes only. Filters are usually not installed.

ASHRAE *Standard* 154 sets minimum exhaust airflow requirements for Type II hoods based on the duty rating of the appliance underneath the hood. Table 8 classifies Type II appliances as either light or medium duty, and Table 9 gives minimum net airflow requirements.

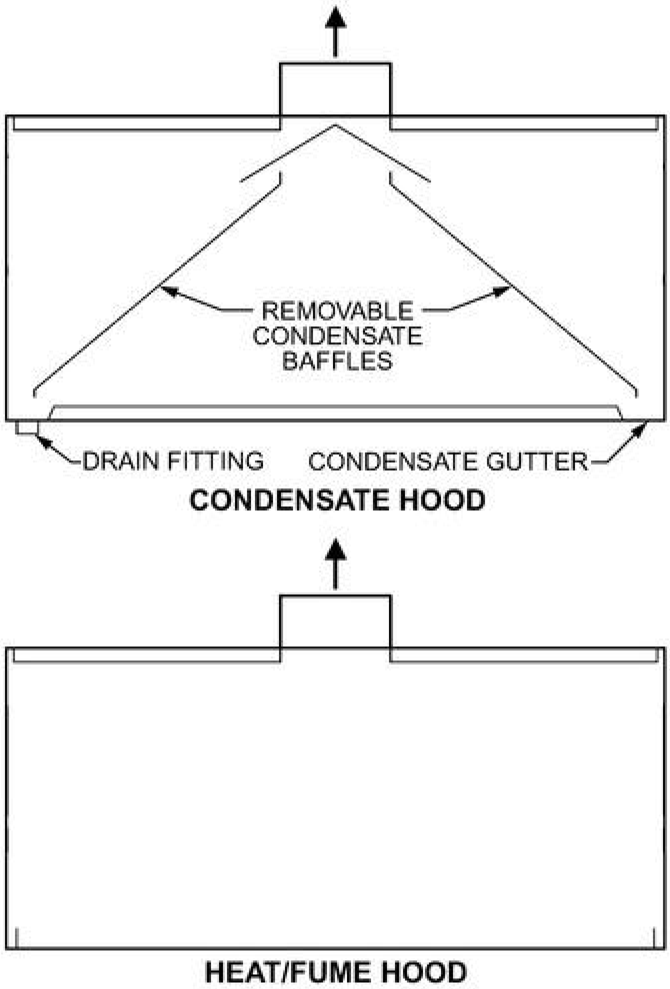


Figure 12. Type II Hoods

Table 8 Type II Hood Duty Classification by Appliance Type

Appliance Description	Size
Hood Not Required	
Cabinet, holding, electric	All
Cabinet, proofing, electric	All
Cheesemelter, electric	All
Coffee maker, electric	All
Cooktop, induction, electric	All
Dishwasher, door-type rack, hot-water sanitizing, heat recovery and vapor reduction, electric	All
Door-type rack, chemical sanitizing, heat recovery and vapor reduction, electric	All
Door-type dump and fill, hot-water sanitizing, electric	All
Door-type dump and fill, chemical sanitizing, electric	All
Pot and pan, hot-water sanitizing, heat recovery and vapor reduction, electric	All
Powered sink, electric	All
Under-counter, chemical sanitizing, electric	All
Under-counter, electric	All
Undercounter, hot-water sanitizing, heat recovery and vapor reduction, electric	All
Drawer warmer, 2 drawer, electric	All
Egg cooker, electric	All
Espresso machine, electric	All
Grill, panini, electric	All
Hot dog cooker, electric	All

Hot plate, countertop, electric	All
Ovens, microwave, electric	All
Popcorn machine, electric	All
Re-thermalizer, electric	All
Rice cooker, electric	All
Steam table, electric	All
Steamers, bun, electric	All
Steamer, compartment atmospheric, countertop, electric	All
Compartment pressurized, countertop, electric	All
Table, hot food, electric	All
Toaster, electric	All
Waffle iron, electric	All
Light-Duty Type II Hood[a,c]	
Kettle, steam jacketed, tabletop, electric, gas and direct steam	< 76 L
Oven, convection, half-size, electric and gas (non-protein cooking)	All
Pasta cooker, electric	All
Re-thermalizer, gas	All
Rice cooker, gas	All
Steamer, atmospheric, gas	All
Pressurized, gas	All
Atmospheric, floor-mounted, electric	All
Pressurized, floor-mounted, electric	All
Kettle, steam-jacketed floor mounted, electric, gas, and direct steam	< 76 L
Medium-Duty Type II Hood[a,c]	
Dishwasher, conveyor rack, chemical sanitizing	All
Conveyor rack, hot water sanitizing	All
Door-type rack, chemical sanitizing	All
Door-type rack, hot water sanitizing	All
Pot and pan, hot-water sanitizing	All
Pasta cooker, gas	All
Steam-jacketed kettle, floor mounted, electric and gas	< 76 L

[b]

Source: ASHRAE *Standard* 154-2016; Table 2.

[a] A hood should be provided for an electric appliance if it produces 5 mg/m^3 of grease or more when measured at 236 L/s.

[b] Where hoods are not required, the additional heat and moisture loads generated by such appliances should be accounted for in the sensible and latent loads for the HVAC system.

[c] Where recirculating systems or recirculating hoods are used, the additional heat and moisture loads generated by such appliances should be accounted for in the sensible and latent loads for the HVAC system.

Ventilation Rates for Hooded Door Dishwashers

The ventilation rates for high-temperature sanitizing door-type dish machines in the model codes are inadequate to capture and contain the heat and steam from the dishwashing operation. The exhaust rates of 154 and 310 L/s per metre of hood in the IMC and UMC (*Uniform Mechanical Code*; IAPMO 2018), respectively, often do not capture the heat and steam released from the machine. The minimum recommendation is 464 L/s per metre of hood for canopy hoods over high-temperature sanitizing door-type machines. Front and side overhangs are critical for capture of the thermal plume from door-type machines, 305 mm on the side and front are the minimum recommendation.

Table 9 Minimum Net Exhaust Airflow Requirements for Type II Hoods

	Minimum Net Exhaust Flow Rate per Linear Hood Length, L/(s·m)	
Type of Hood	**Light-Duty Equipment**	**Medium-Duty Equipment**

Wall-mounted canopy	310	465
Single island	620	775
Double island (per side)	388	465
Eyebrow	388	388
Back shelf/pass-over	310	465

Source: ASHRAE *Standard* 154-2011.

Door-type machine operations are good candidates for demand control kitchen ventilation (DCKV) systems. The DCKV system should initialize ramp-up at the beginning of the wash cycle, not the end of the cycle, when it is too late to capture the thermal plume from the door opening. Door-type dishwashers are also good candidates for exhaust air heat recovery in the ventilation system. The exhaust air steam is clean and hot and heat exchangers can take advantage of latent heat in addition to sensible heat. Low-temperature sanitizing door-type machines should not be placed directly under return air grilles.

Ventilation for Conveyor Dish Machines

Conveyor dish machines' exhaust ductwork are typically pant-leg connections to vent cowls at the entrance and exit of the dish machine. The exhaust airflow rates at the vent cowls are typically 94 L/s at the entrance and 189 L/s at the exit. The actual airflow rates are difficult to measure in the field and are rarely verified. Therefore, a visual capture and containment assessment is recommended, with field adjustment as necessary to maintain capture and containment at the entrance and exit. Even with a well-balanced airflow, convective loads escape from the curtains, door seals, and drains. These other convective loads could contribute more than 4690 W (with 40% of the load being latent) (PG&E 2011) and should be accounted for in the internal heat load calculation for the dishroom.

As an alternative to a pant-leg exhaust system, a canopy exhaust hood with a minimum ventilation rate of 308 L/s per metre of hood should be considered. The convective load to space can nearly be eliminated if the canopy hood incorporates adequate overhang (305 mm overhang on both sides, and 610 mm overhang on both the front and rear).

Recirculating Systems

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 system, including specific nozzle locations; (3) maintenance, including a specific schedule for cleaning filters, ESP, hood, and fan; 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 standard for a recirculating system is UL *Standard* 710B. Recirculating systems should not be used over gas-fired or solid-fuel-fired cooking equipment.

Designers should thoroughly review NFPA *Standard* 96 requirements and contact a manufacturer of recirculating systems to obtain specific information needed for the design and listing information before incorporating this type of system into a food service design.

Additionally, many jurisdictions have implemented installation guidelines and requirements related to recirculating systems. A local AHJ should be consulted to ensure compliance with any planned recirculating system installation.

In application a recirculating system is typically specified when a Type I or Type II hood is not feasible. Beyond meeting minimum code requirements, the designer must also consider Indoor Air Quality and odor propagation in the space. All manufacturer recommendations on installation should be adhered to when specifying recirculating systems. Although below the 5 mg/m^3 threshold as prescribed by NFPA Standard 96 and UL Standard 710B, a recirculating system will generate emissions that may be objectionable to operators and patrons. Where possible, supplemental exhaust and increased outdoor air to maintain space balance should be considered for removal of emissions and odors. The additional sensible and latent load from the equipment must be considered in all HVAC load calculations. Existing spaces may not have HVAC capacity to offset the load of additional equipment. In practice, these spaces are most often considered for recirculating applications so caution must be exercised to ensure proper operation.

Downdraft Appliance Ventilation Systems

These systems are intended to remove smoke, grease-laden vapors, odors, and other impurities from the air by drawing the cooking effluents away from cooking appliances and downward into ventilation systems. According to UL *Standard* 710B, these systems are used with electric cooking appliances only. A downdraft system listed to UL *Standard* 710B, for recirculating applications, consists of a fire extinguishing system unit, grease filters, interlocks, etc., all contained within a suitable enclosure.

Downdraft systems operate on a different principle than typical exhaust hoods. With a customary exhaust hood, the buoyant thermal plume from cooking rises into the exhaust hood by gravity, provided overhang is sufficient, cross drafts do not interfere, etc., as explained previously. Thereafter, one or more exhaust fans create a low pressure are in the hood plenum, and the exhaust contents are carried outdoors from the hood.

In contrast, downdraft ventilation systems include an exhaust fan that creates a low pressure at an inlet beside or behind a cooking surface, or between two cooking surfaces. The exhaust fan draws cooking effluents, possibly including combustion products, through a grease filter in the exhaust inlet, to be transported outdoors or recirculated into the cooking space.

Downdraft appliance ventilation systems are described and covered by NFPA *Standard* 96, Chapter 15, and if used for recirculation, are listed to UL *Standard* 710B. If used to ventilate processes producing smoke or grease laden vapor, these systems must comply with NFPA *Standard* 96, Chapter 15, which references other requirements in NFPA *Standard* 96:

- Clearance requirements in Section 4.2
- Hood requirements of Chapter 6
- Grease removal device requirements of Chapter 7
- Special-purpose filters listed in accordance with ANSI/UL *Standard* 1046
- Exhaust duct requirements of Chapter 7
- Air movement requirement of 8.2.1.2 and 8.2.2.3
- Fire-extinguishing requirements of Chapter 10 and Section 15.2
- Maintenance requirements of Chapter 11
- Safety requirements of Chapter 12

Important additional requirements are provided by NFPA *Standard* 96, sections 15.1.2 through 15.4.

Caution is advised for application of downdraft ventilation systems to commercial kitchens. Pulling effluent away from a flat-surface griddle is one popular application of these systems, particularly in Asian-style steakhouses, where the griddles are used intermittently and the exhaust inlet is slightly close to the edges of the cooking surface. More challenging is trying to pull vapors from the tops of commercial cooking vessels, such as on range tops, because cooking effluents might be emitted above and out of reach of the downdraft inlet suction. For gas appliances, also remember that air movement created by downdraft inlet suction might be sufficient to interfere with the operation of nearby gas burners.

Field Performance Testing

Once kitchen ventilation systems have been installed, it is important to verify that they operate correctly. ASHRAE *Standard* 154 describes performance testing for both Type I and Type II hood applications. For Type II hoods, the requirement is that the hood must be operating at the minimum airflow shown in Table 9. For Type I hoods, all appliances must be turned on and either actual or simulated cooking must be performed to verify that the hood system has achieved proper capture and containment.

1.7 COOKING EFFLUENT GENERATION AND CONTROL

Air quality, fire safety, labor cost, and maintenance costs are important concerns involved with 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 within a duct 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, which is expensive and disruptive to kitchen operation. It also depends on frequent duct inspections and regular cleaning. Grease build-up on fans, fire nozzles, roofs, and other ventilation equipment can be costly in additional maintenance and replacement costs. From an energy and sustainability perspective, it is desirable to reduce the atmospheric emissions and achieve the highest grease extraction or destruction with the lowest energy costs possible. For mechanical extractors, the pressure drop of the filters is the predominant driver for energy usage, whereas for other control systems there may be electrical components or water use that needs to be evaluated. Figure 13 presents some design guidance for what filtration may be desirable under various exhaust temperature and/or duty level situations.

Table 10 Recommended Duct-Cleaning Schedules

Type or Volume of Cooking	Inspection Frequency
Solid fuel	Monthly
High-volume cooking (gas charbroiler or wok cooking)	Quarterly
Moderate-volume	Semiannually
Low-volume (churches, day camps, seasonal businesses)	Annually

Source: Reproduced with permission from the 2017 edition of NFPA 96, Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations, Copyright© 2016, National Fire Protection Association. All rights reserved. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety which can be which can be viewed for free access or purchased through the NFPA web site at www.nfpa.org.

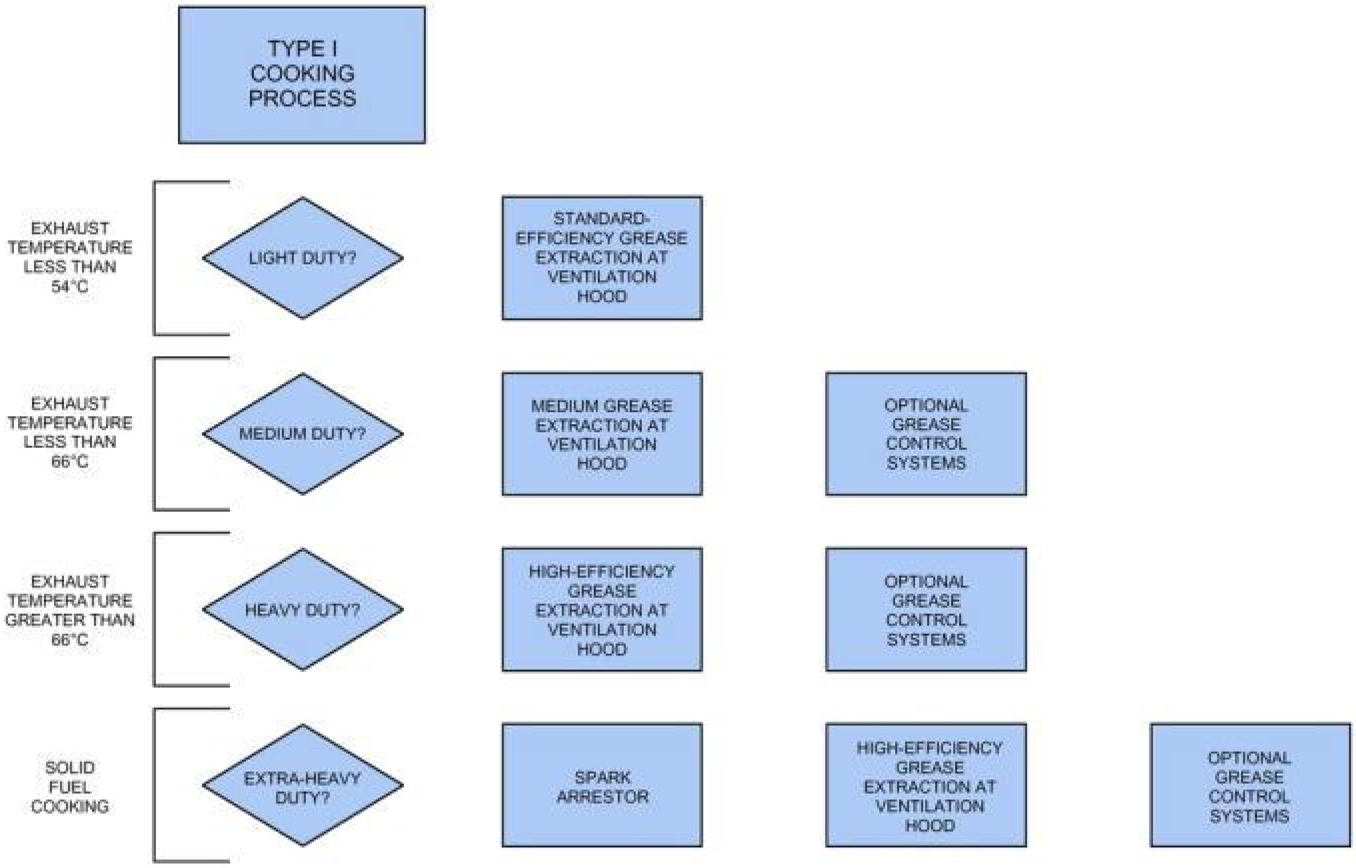


Figure 13. Typical Filter Guidelines Versus Appliance Duty and Exhaust Temperature

Another issue that commonly comes up during kitchen design and operation is how often ductwork needs to be cleaned in restaurants. Table 10 presents inspection schedules adapted from Table 11.4 of NFPA *Standard* 96.

Effluent Generation

During cooking operations on appliances, effluent is generated, which includes water vapor and organic material (in both particulate and vapor form) released from the food. The combustion of fuel and grease contributes to the mixture released from the cooking, including condensable and noncondensable gases. For solid-fuel cooking, the effluent mixture contains not only toxic contaminants, but also condensable creosote (which has a lower flash point and increases risk of duct fires).

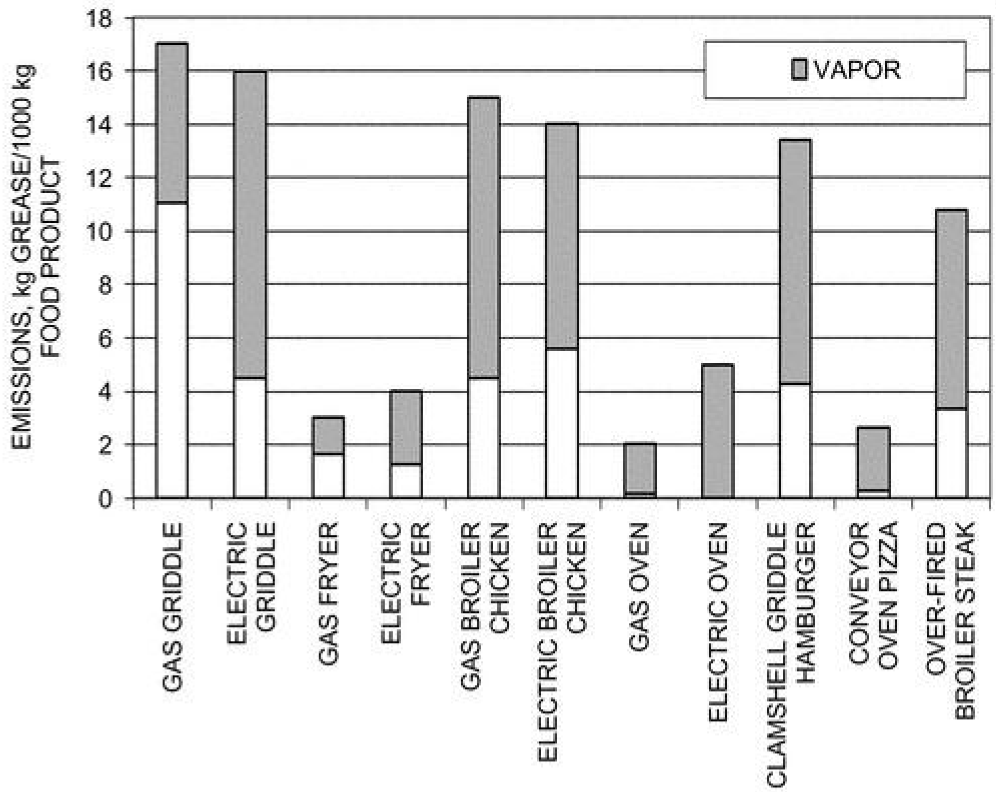


Figure 14A. Grease in Particulate and Vapor Phases for Commercial Cooking Appliances with Total Emissions Approximately Less Than 50 kg/1000 kg of Food Cooked

Particle Size Comparisons (from Exhaust Systems). 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. Figures 14A and 14B show 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, gas underfired broilers (referred to as "gas broilers" in Figures 14A and 14B) 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 gas 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 14C shows the measured plume volumetric flow rate entering the hood. In general, gas appliances have slightly larger flow rates than electric because additional products of combustion must be vented. Gas underfired and electric broilers have plume flow rates considerably larger than the other appliances shown. Effluent flow rates from gas underfired and electric broilers are approximately 100 times larger than the actual volumetric flow rate created by vaporizing moisture and grease from food. The difference is caused by ambient air entrained into the effluent plume before it reaches the exhaust hood.

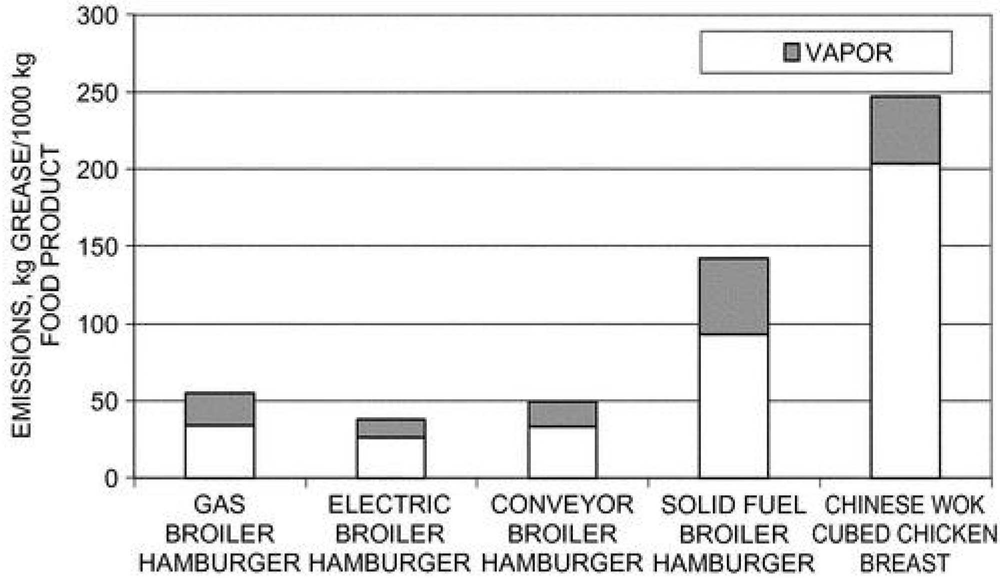


Figure 14B. Grease in Particulate and Vapor Phases for Commercial Cooking Appliances with Total Emissions Approximately Greater Than 50 kg/1000 kg of Food Cooked

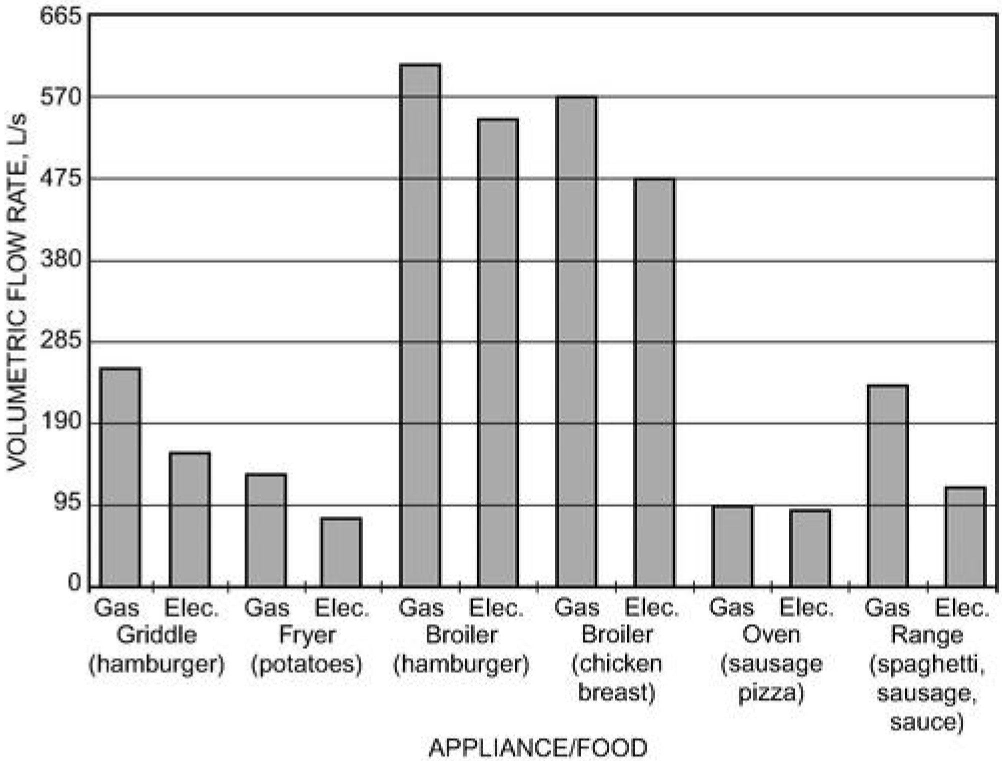


Figure 14C. Plume Volumetric Flow Rate at Hood Entrance from Various Commercial Cooking Appliances (Kuehn et al. 1999)

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.

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 15 illustrates a heated plume with and without cooking effluent as it rises from heated cooking appliances. Figure 15A shows two gas underfired broilers 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. Figures 15B and 15C show the hot-air plume without cooking, visualized using a schlieren optical system, under full capture and spillage conditions, respectively.

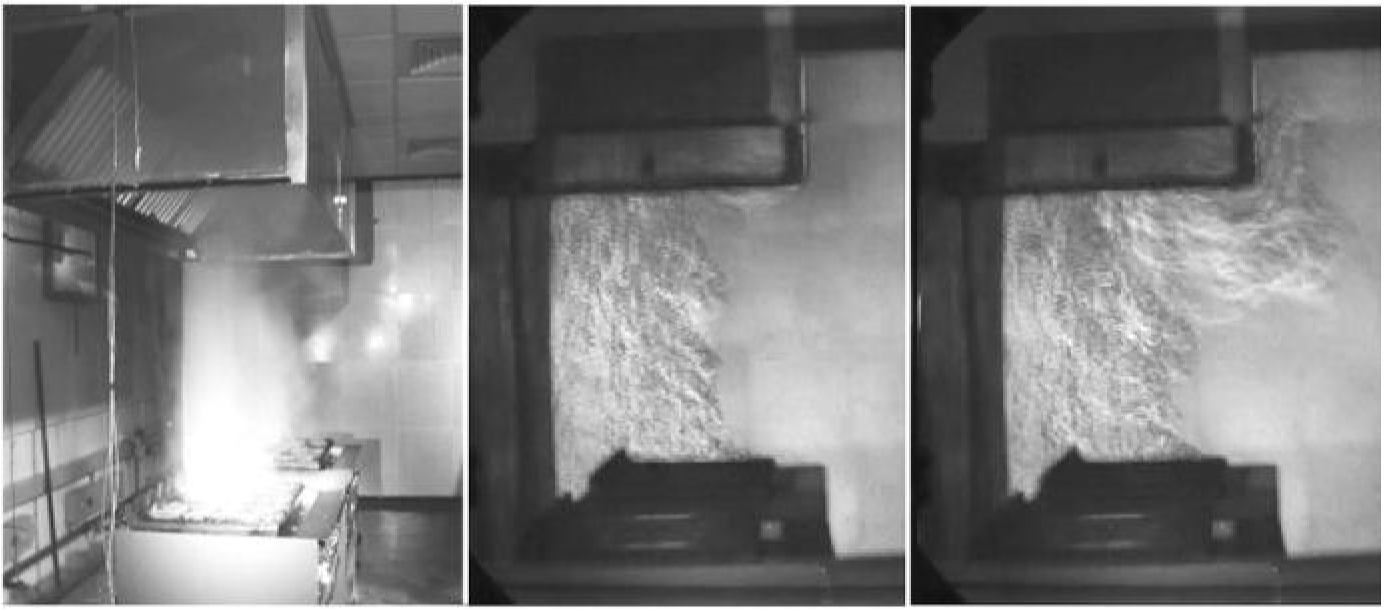


Figure 15. Hot-Air Plume from Cooking Appliances under Wall-Mounted Canopy Hood

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). 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.

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.

The reported grease extraction efficiency of mechanical filtration systems (e.g., baffle filters and slot cartridge filters) may reflect the particulate removal performance of these devices. These devices are listed for their ability to limit flame penetration into the plenum and duct. Grease extraction performance can be evaluated using ASTM *Standard* F2519. Smaller aerodynamic particles (<2.5 μm) are not easily removed by mechanical extractors. If these particles must be removed, a pollution control 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.

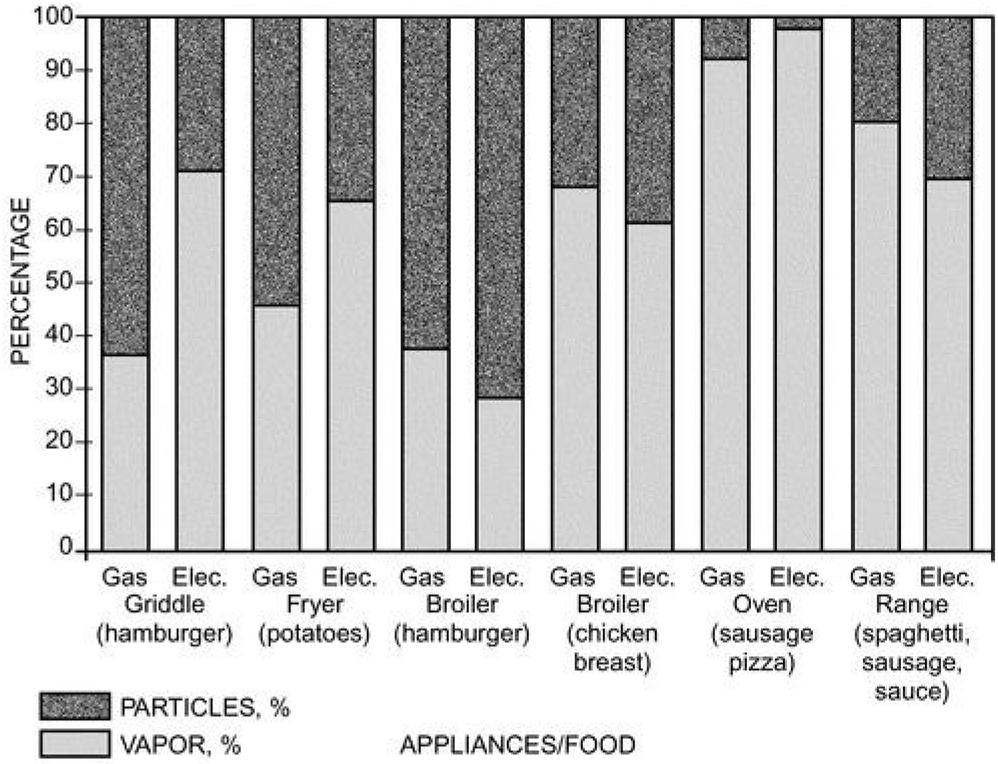


Figure 16. Particulate Versus Vapor-Phase Emission Percentage per Appliance (Average) (Gerstler et al. 1998)

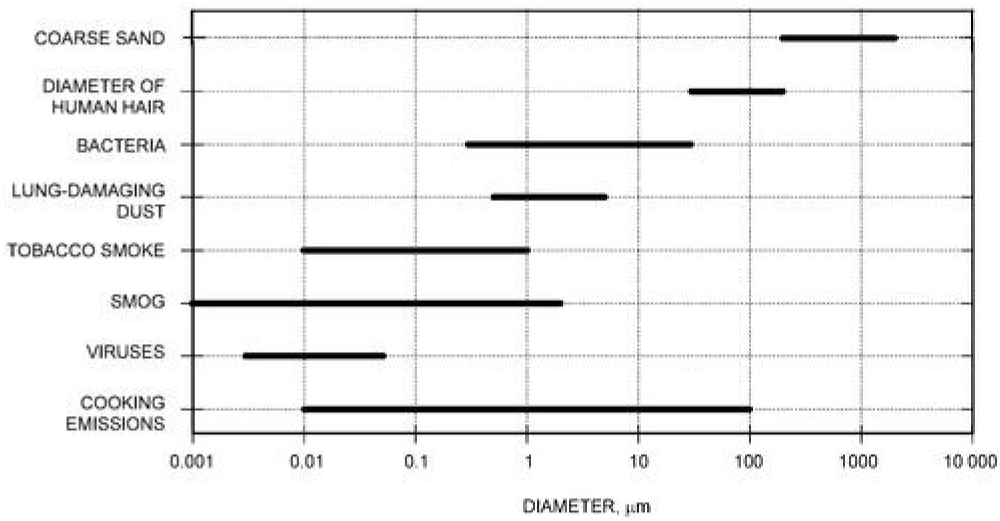


Figure 17. Size Distribution of Common Particles

ASHRAE research project RP-745 (Gerstler et al. 1998) found that a significant proportion of grease effluent may be in vapor form (Figure 16), which is not removed by mechanical extractors.

Grease Extraction

The particulate range from cooking operations ranges from 0.01 to 100 µm. Different cooking operations have different ranges of particle sizes in the cooking plume and have been measured for many appliances (Gerstler et al. 1998; Kuehn et al. 2008). Grease particulates larger than 20 µm are too heavy to remain airborne and drop out of the airstream. Figure 17 compares the size of particles from kitchen exhaust to common items.

Each combination of food product, cooking equipment, and cooking temperature creates a unique particle emissions profile, these profiles change over time during the cooking process. For example, the initial drop of French fries into a fryer gives off a short blast of large particles, whereas cooking a hamburger on a griddle gives off a continuous stream of particles and vapor. Burgers cooked on a broiler tend to burn and emit very small particles (< 1 µm in size).

Variations in the food product itself can also change the emissions of a cooking process. Hamburger with 23% fat content produces more grease than a 20% fat 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 18 and 19 show typical particle emission profiles for a gas griddle and gas underfired broiler both cooking hamburgers (Kuehn et al. 1999).

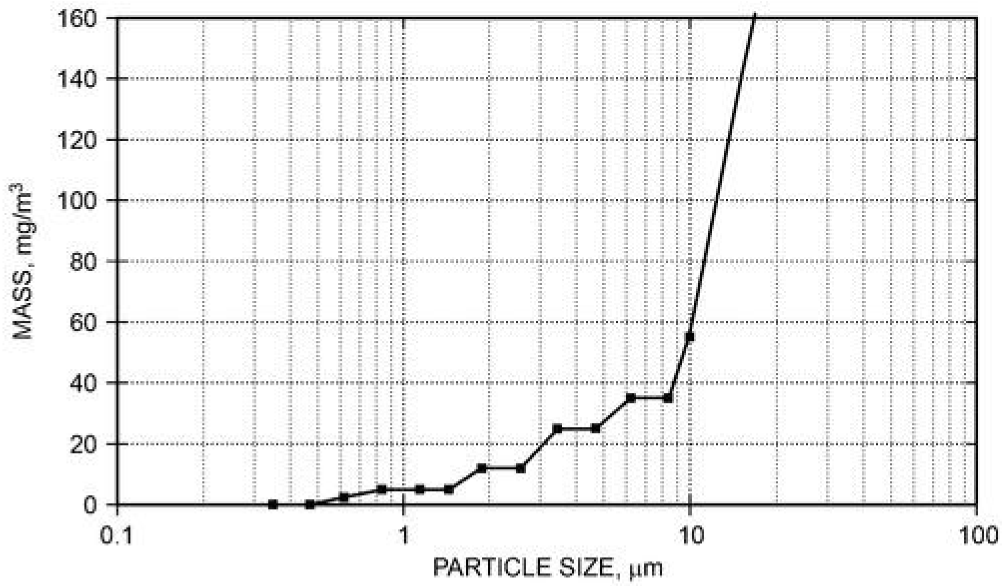


Figure 18. Gas Griddle Mass Emission Versus Particle Size (Kuehn et al. 1999)

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 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 20.

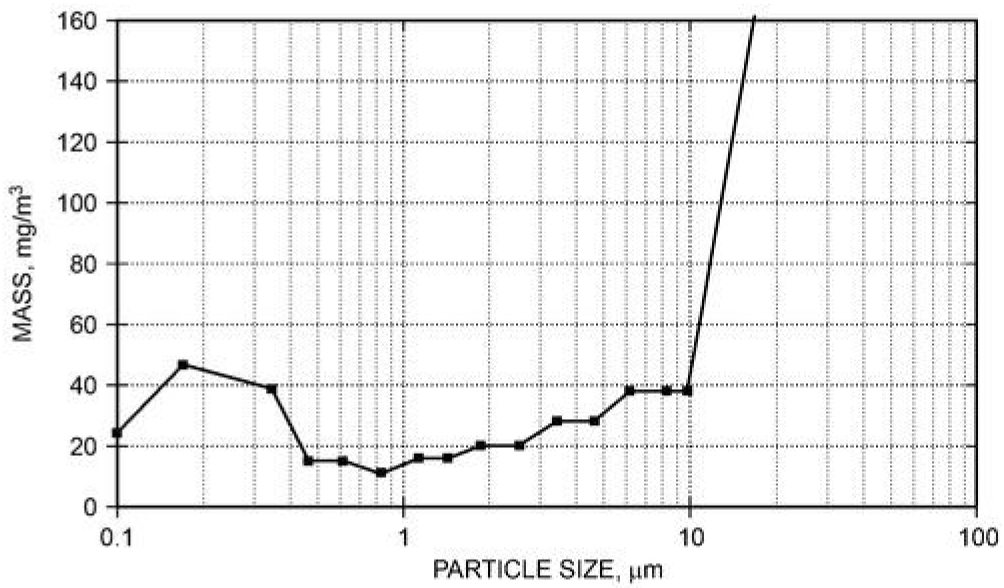


Figure 19. Gas Underfired Broiler Mass Emission Versus Particle Size (Kuehn et al. 1999)

Extraction efficiencies must be compared at the same airflow per linear length of filter. 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.

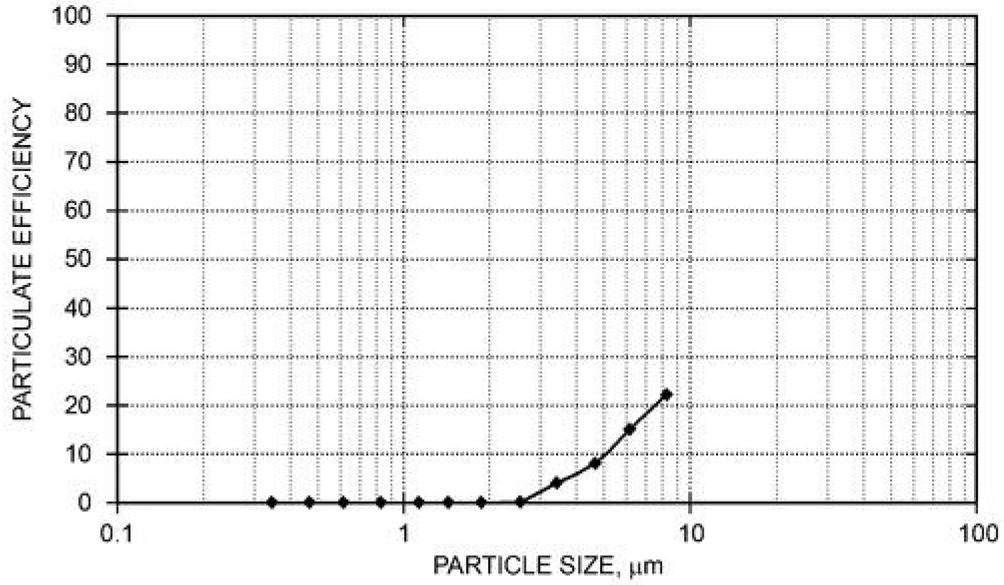


Figure 20. Baffle Filter Particle Efficiency Versus Particle Size (Kuehn et al. 1999)

To demonstrate what a filter fractional efficiency means with an actual cooking process, the gas underfired broilers (referred to as "charbroiler") emissions curve and the baffle filter efficiency curve have been plotted on one graph in Figure 21. The area under each emission curve is representative of the total particulate emissions for the gas underfired broiler. 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 duct. The area under the "charbroiler after baffle" curve represents the amount of grease particulate exhausted into the duct.

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 duct and fan. However, with elevated temperatures in the exhaust airstream, vapor may pass through and exit to the atmosphere.

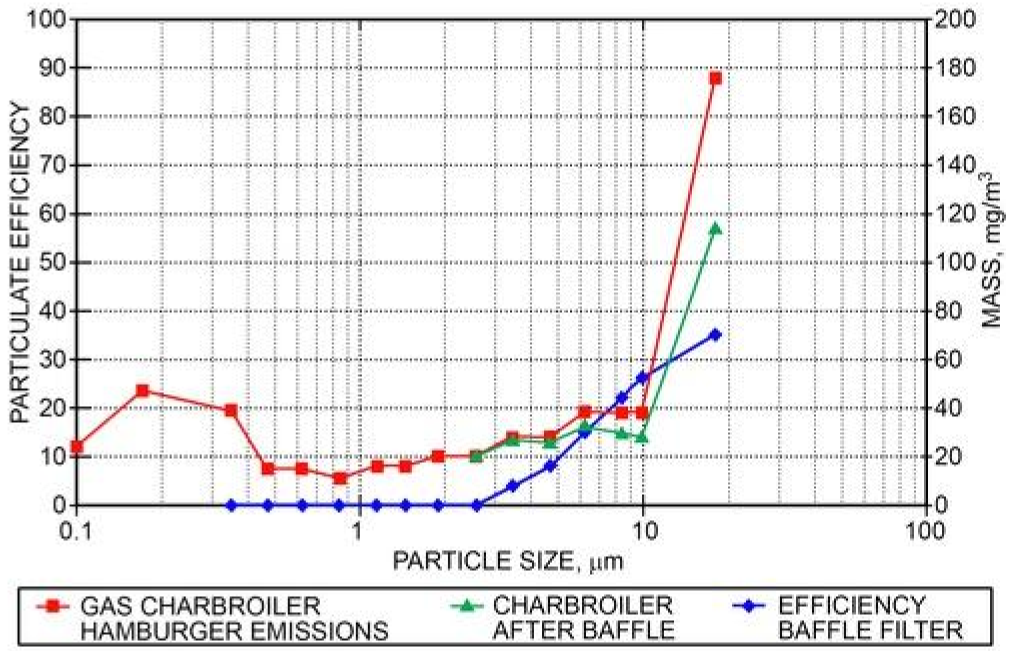


Figure 21. Baffle Filter Particle Efficiency Versus Particle Size (Kuehn et al. 1999)

Higher efficiency at a specific particle size may not be the only selection criteria for grease extraction. From an energy and sustainability standpoint, the ideal goal would be to have the highest grease extraction at the lowest pressure drop possible. Smaller particles can only be removed by shifting the efficiency curve towards the left.

More effective devices reduce grease build-up downstream of the hood, lowering the frequency of duct cleaning and reducing the fire hazard. Having higher-efficiency grease removal devices in the hood reduces the maintenance of downstream control equipment.

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 the outdoors 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. See Chapter 12 of the 2021 *ASHRAE Handbook—Fundamentals* for more information.

The following technologies are 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 outdoors.
- As the ionizer section becomes dirty, efficiency drops because the effective ionizer surface area is reduced.
- Under heavy loading, the unit may shut down because of voltage drop.

Ultraviolet (UV) Destruction. This system uses ultraviolet light to chemically convert the grease into an inert substance and ozone. Construction (not performance) is evaluated for safety in accordance with UL *Standard* 710C. RP-1614: Developing a Test Method to Determine the Effectiveness of UVC Systems on Commercial Cooking Effluent, was recently completed and includes information for quantifying the performance and proper application of this technology.

- Requires adequate exposure time for chemical reactions.
- Its effectiveness is dependent on the food product being cooked as well as the type of cooking process.
- 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 pellets or granules.

- 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 because of high temperature requirement if integrated into the hood (can be cost-effective at the appliance level).

1.8 REPLACEMENT (MAKEUP) AIR SYSTEMS

In hood systems, where air exhausted through the hood is discharged to the outdoors, the volume of air exhausted must be replaced with uncontaminated outdoor air. Outdoor 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), prevention of kitchen odors migrating to adjacent building spaces, and/or maintaining a comfortable building environment. Proper pressurization enhances the building environment by preventing suction of unfiltered and/or unconditioned outdoor air into the building envelope through doors, windows, or air handlers. IMC (ICC 2018a) 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 sources. This electrical interlock prevents excessive negative or positive pressures created by the exhaust fan or replacement air unit operating independently.

Table 11 Outdoor Air Requirements for Dining and Food Preparation Areas

Facility Type	Airflow Rate, L/s per person	Maximum Occupancy, persons/100 m^2
Restaurant dining area	3.8	70
Cafeterias and fast food dining area	3.8	100
Bars/cocktail lounges	3.8	100
Kitchen (cooking) spaces	3.8	20

Note: All areas are assumed nonsmoking.
Source: ASHRAE *Standard* 62.1.

Indoor Environmental Quality

Traditionally, the primary purpose of replacement air has been to ensure proper operation of the hood. Kitchen thermal comfort and indoor environmental quality (IEQ) have been secondary. In some applications, thermal comfort and IEQ can be improved through adequate airflow and proper introduction of replacement air. In many of today's applications, outdoor air that meets IEQ standards is the most energy-efficient source for kitchen hood replacement air.

Table 11 gives ASHRAE *Standard* 62.1 requirements for outdoor air per person; these requirements may be increased or decreased in certain areas if approved by the authority having jurisdiction. Outdoor air requirements affect HVAC system sizing and may require another means of introducing outdoor air. A further requirement of *Standard* 62.1, that outdoor 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 due to cooking ventilation rates.

Replacement Air Introduction

Replacement air may be introduced into the building through dedicated makeup air units, conventional HVAC apparatus, dedicated hood-system makeup air units (discussed in the section on Air Distribution), or in very limited climates, ventilators that include no conditioning means.

Dedicated Makeup Air Units. These units are specifically designed to heat, dehumidify, or cool 100% outdoor air. These dedicated units typically include modulating, heating, dehumidification, and cooling systems that react to outdoor air conditions and prevent cycling of these conditioning systems. Cycling leads to space discomfort and higher unit energy consumption. Hot-gas reheat (HGRH) may also be included to aid in continuous dehumidification (when required by outdoor air conditions) while maintaining space comfort. See Chapter 28 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* for more information on makeup air units.

Using enthalpy or temperature control for determining dedicated makeup air unit operation is recommended. These controls turn compressor(s), water supply, or heat sources off when outdoor air conditions warrant, while maintaining kitchen comfort, thus conserving energy and saving money without the use of additional economizer damper systems.

Conventional HVAC Units. Conventional HVAC units require fixed outdoor air intakes or economizer-controlled outdoor air dampers when they (1) supply outdoor air to meet spaces' ventilation requirements, (2) are adjacent to the kitchen area, and (3) only secondarily transfer the outdoor component of the total airflow to the kitchen. To alleviate any potential overpressurization occurrences, 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 outdoor air increases, the increasing pressure in the system opens the relief damper, so that the return air volumetric rate is only enough to maintain approximately the amount of design supply 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 outdoor air intakes must be set to allow the required amount of replacement air. Outdoor 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 outdoor conditions are within economizer range, the outdoor damper may be opened to allow greater amounts of outdoor air. The maximum setting for outdoor air dampers in unitary HVAC units is typically 25 to 30% of total unit air volume when the units are operating in their heating or cooling (i.e., noneconomizer) mode. Field experience has shown 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 outdoor 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. Outdoor air must be considered during initial unit selection to obtain desired unit operation and space comfort. The space in which the hood is located should be kept 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.

In climates with higher summer dew-point design conditions, consider adding active dehumidification (such as hot-gas reheat) for units supplying outdoor air for ventilation at rates greater than 10% of unit total airflow.

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 outdoor 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, outdoor 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.

Kitchen supply air is outdoor 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 because it also provides comfort conditioning for the occupants.

Makeup air is outdoor air introduced through a system dedicated to providing 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 2018a) requires makeup air be conditioned to within 5.5 K of the kitchen space, except when introducing replacement air that 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 heating include direct and indirect gas-fired units, hot-water coils (with freeze protection), and, in some cases or geographic areas, electric resistance heating. When cooling is provided, the outdoor air design conditions must be considered. A low-dew-point design is required for effective use of evaporative coolers. Higher-dew-point design temperatures may require water or direct exchange (DX) coils for cooling and/or dehumidification. Temperature of makeup air introduced varies with distribution system and type of operation.

Transfer air is outdoor air, introduced through the HVAC or ventilating apparatus, dedicated to comfort conditioning and ventilation requirements of a space adjacent to the area in which the hood is located. The device providing transfer air must operate and supply outdoor air whenever 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 at velocities that may be detrimental to food service processes. 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 outdoor air may be transferred for replacement air. The IMC (ICC 2018a) recognizes the use of transfer air as a replacement air source. In large 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. 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 may enhance or degrade hood performance. Systems that use a combination of kitchen 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.

Hood-Supplied Replacement Air (Compensating Hoods). A common way of distributing replacement air is through compensating systems that are integral with the hood. Figure 22 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 of configurations that include perimeter supply.

Brohard et al. (2003) investigated the effects of six methods of introducing replacement air on three hood styles. Three hood types were tested: (1) wall-mounted canopy, (2) island-mounted canopy, and (3) proximity (back shelf). Gas underfired broilers and gas griddles, respectively representing heavy-duty and medium-duty appliances, were tested. Idle and emulated cooking conditions were also tested. The MUA strategies included (1) displacement ventilation (base case), (2) ceiling diffuser, (3) hood face diffuser, (4) air curtain diffuser, (5) back wall supply, and (6) short-circuit supply. The influences of air mass disturbances (drafts) and tapered side panels were also investigated. Each replacement 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 replacement 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).

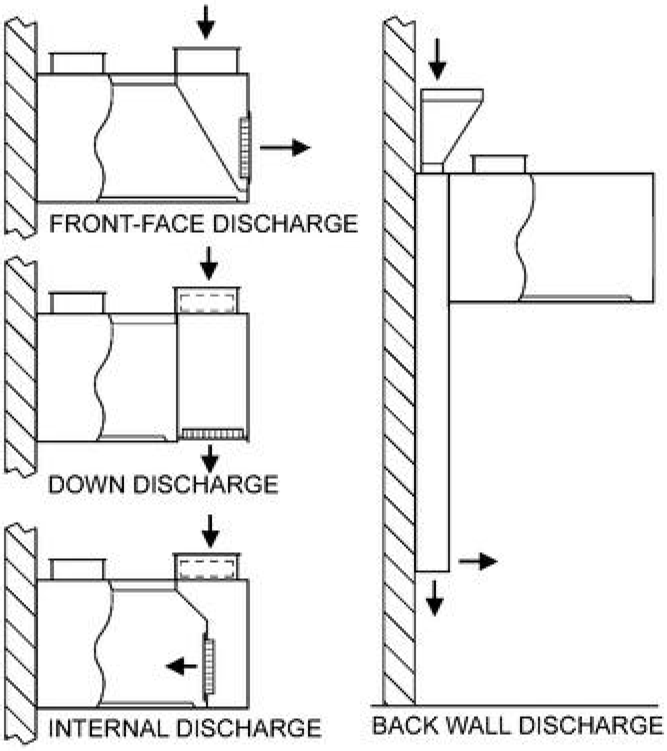


Figure 22. Compensating Hood Configurations

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 gas or electric broilers. 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 23 by the schlieren flow visualization recorded during a test of a wall-mounted canopy hood operating over two gas 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.

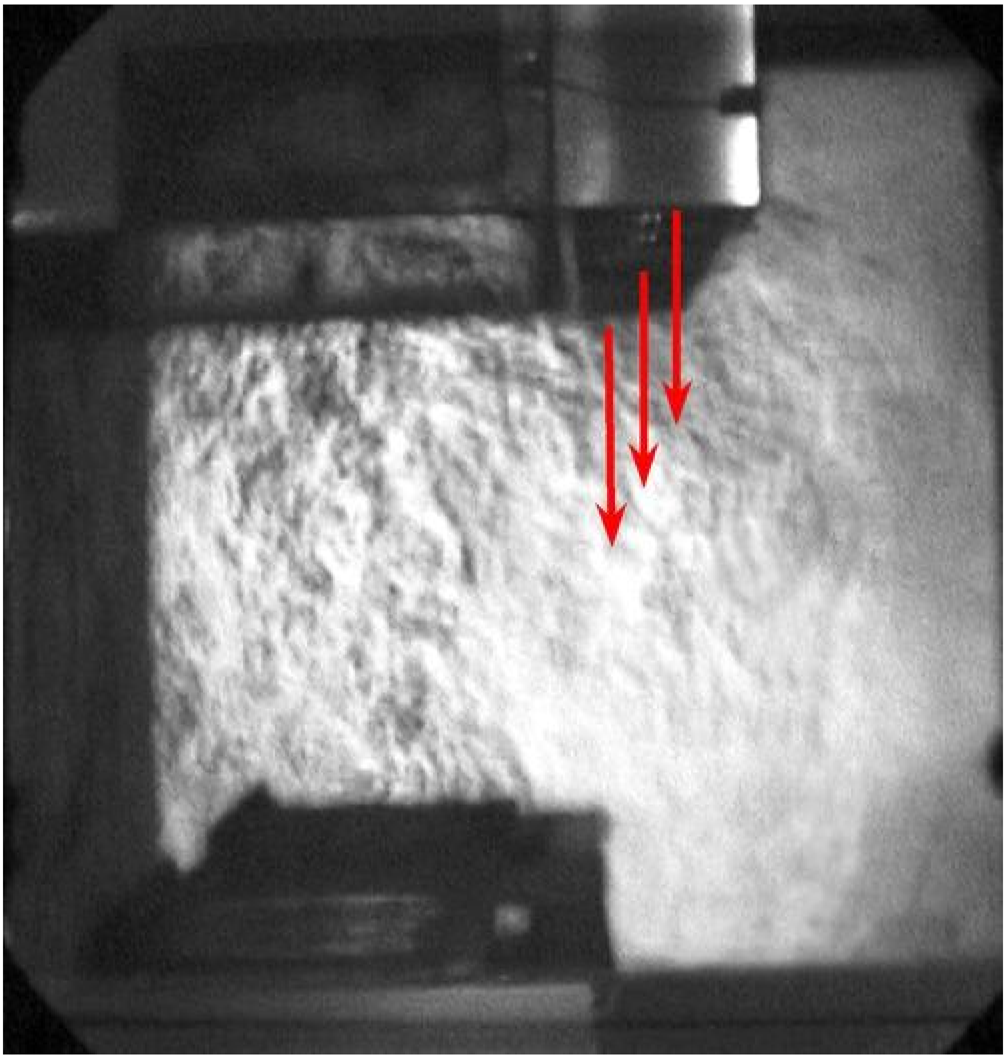


Figure 23. Schlieren Image Showing Thermal Plume Being Pulled Outside Hood by Air Curtain (Brohard et al. 2003)

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 discharge, air volume and discharge velocity dictate how far into the space the makeup 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 24). 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 replacement 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.

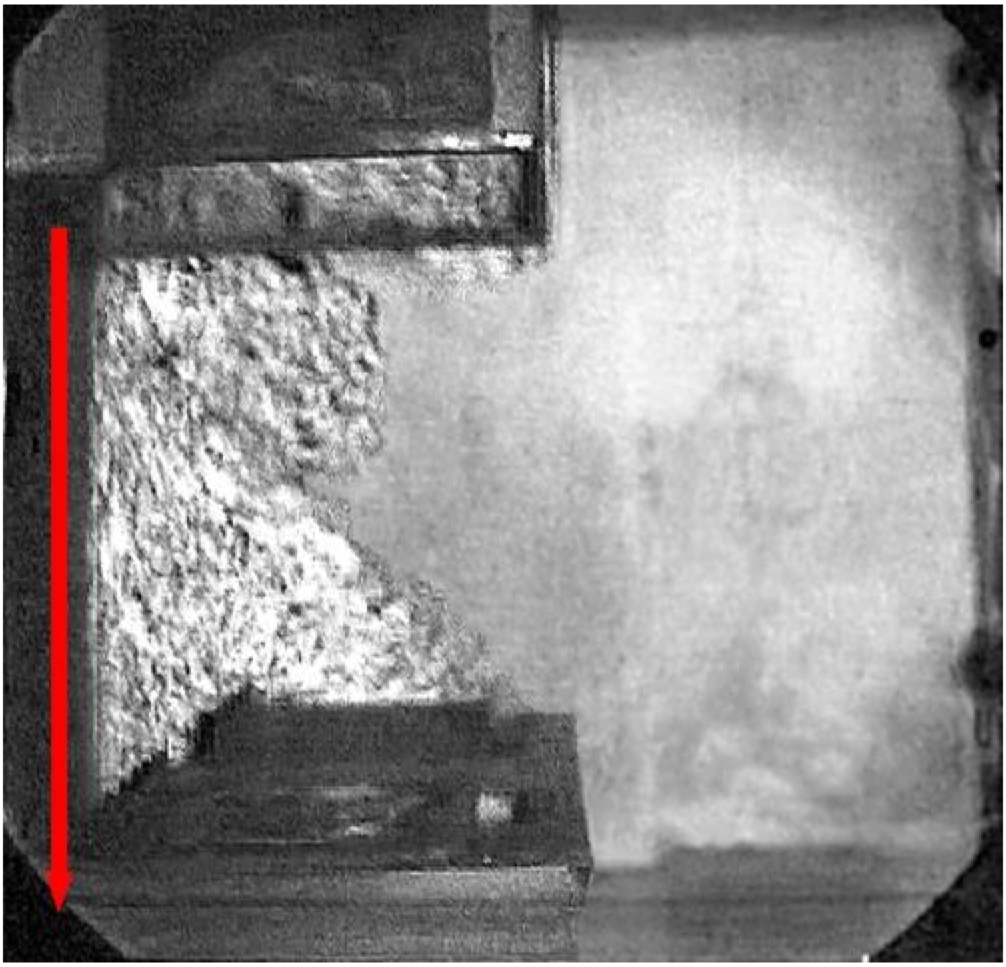


Figure 24. Schlieren Image Showing Thermal Plume Being Captured with Back-Wall Supply (Brohard et al. 2003)

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 25 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 replacement air supply to interfere with hood capture and containment. In general, face discharge velocities should not exceed 0.75 m/s (i.e., replacement air flow rate divided by gross discharge area) and should exit the front face in a horizontal direction.

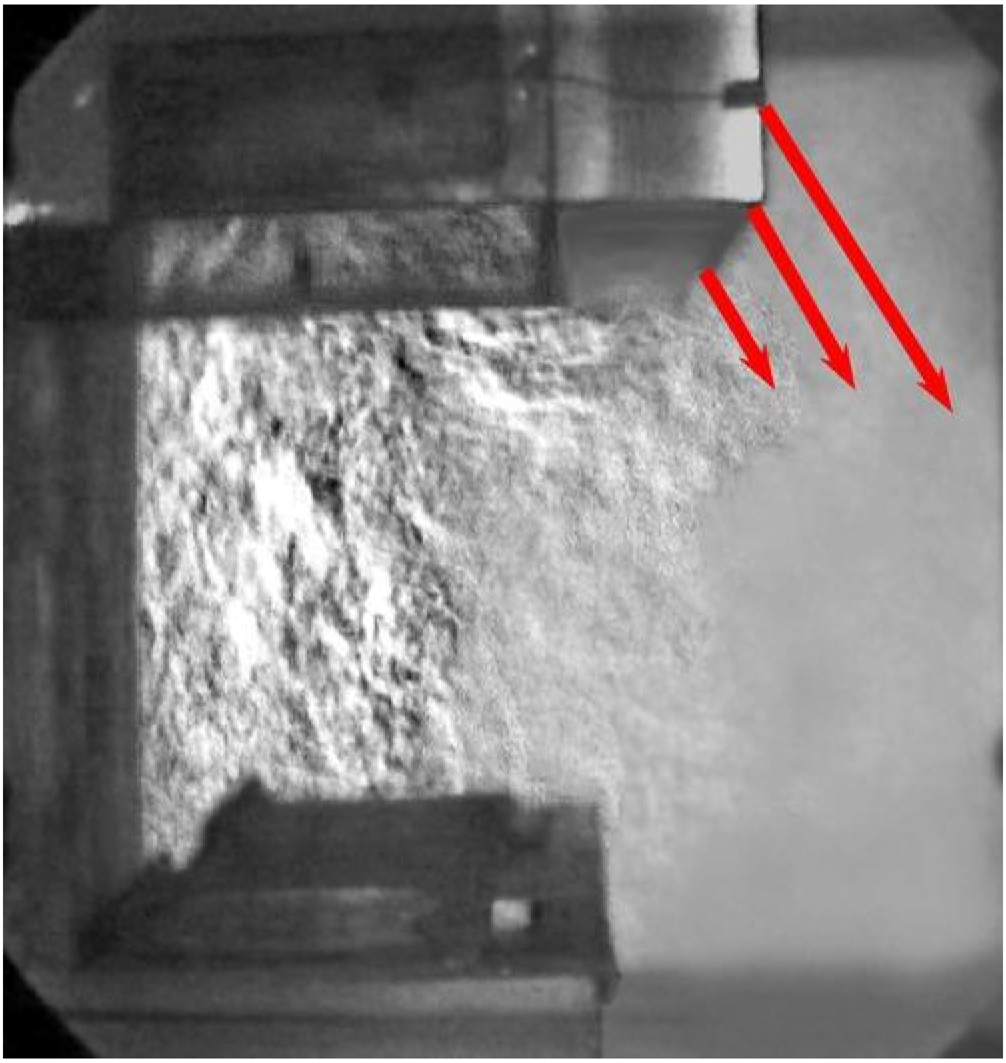


Figure 25. Schlieren Image Showing Thermal Plume Being Pulled Outside Hood by Front Face (Brohard et al. 2003)

Internal Makeup Air. This method, also known as **short circuit,** introduces makeup 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 makeup air) is less than the plume volume, part of the plume may spill out of the hood. Internal makeup 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 (2018a) 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 26). ASHRAE *Standard* 154 limits the quantity of internal replacement air to no more than 10% of the exhaust airflow. Additionally, the introduction of untempered makeup air results in uncomfortable kitchen conditions. Independent research (Brohard et al. 2003) 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 performance problems of each of the individual types, and combining them tends to compound these issues.

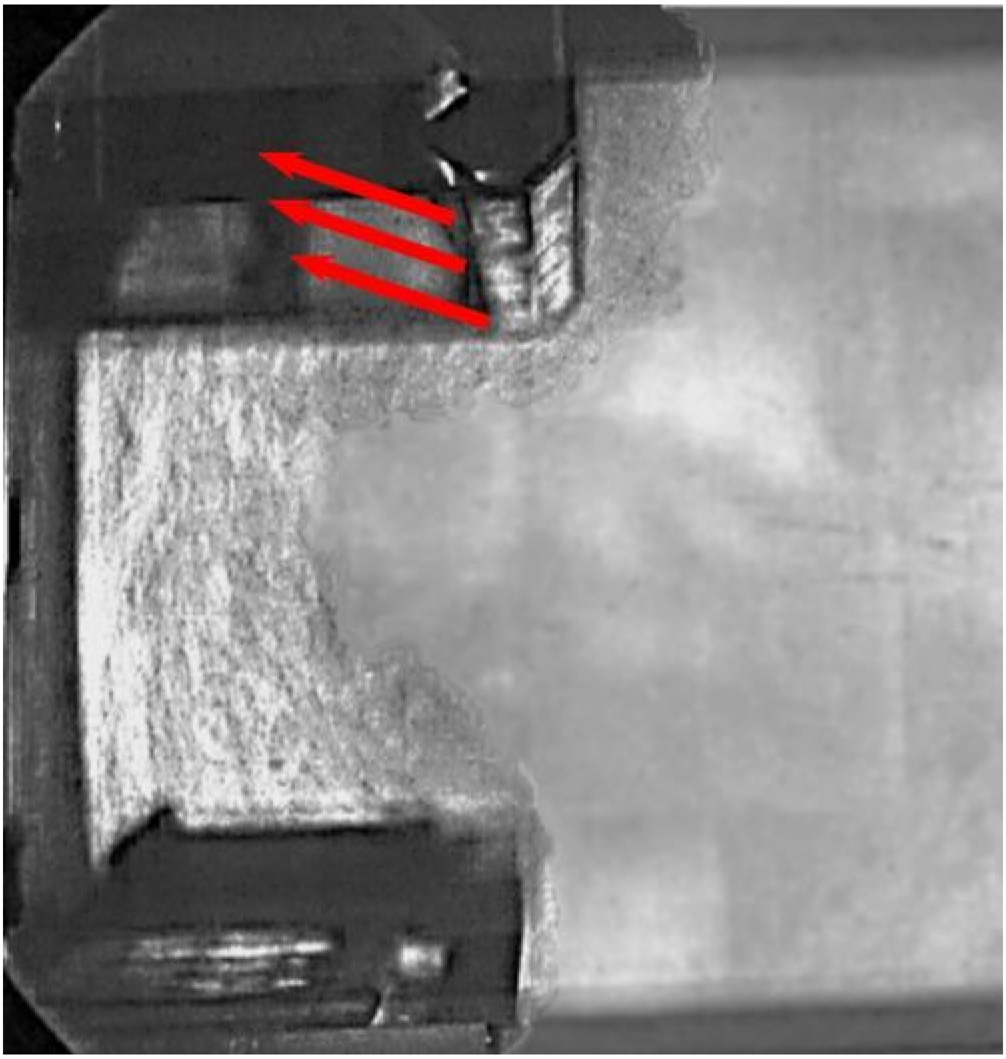


Figure 26. Schlieren Image Showing Thermal Plume Being Displaced by Short-Circuit Supply, Causing Hood to Spill (Brohard et al. 2003)

Perforated Perimeter Supply. Perforated perimeter supply is similar to a front-face supply, but the air is directed downward, as in Figure 27, 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 airflow 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 replacement 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. In all cases, the velocity downward 50 mm above the lower edge of the hood should not exceed 0.4 m/s.

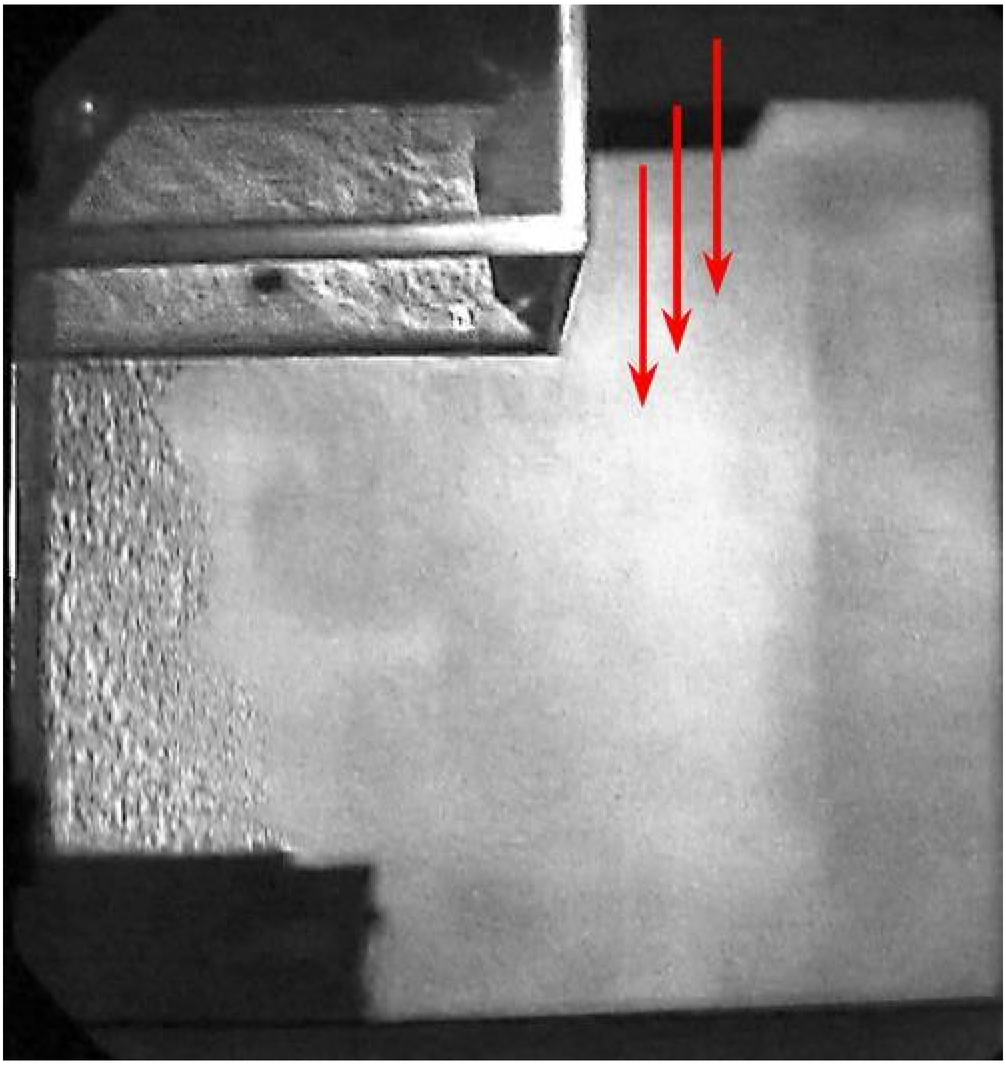


Figure 27. Schlieren Image Showing Effective Plume Capture with Replacement Air Supplied Through 400 mm Wide Perforated Perimeter Supply, Shown with Additional Front Overhang (Brohard et al. 2003)

Room-Supplied Makeup Air (Diffusers and Grilles). 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. For more information on diffusers, see Chapter 20 of the 2017 *ASHRAE Handbook—Fundamentals*, Chapter 20 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment*, and Chapter 58 of this volume. Typical devices include the following.

Directional Ceiling Diffusers. Air from these two- or three-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 Directional Ceiling Diffusers. Four-way directional diffusers located close to kitchen exhaust hoods (Figure 28) can have a detrimental effect on hood performance, particularly when flow through the diffuser approaches its design limit. They are not recommended within 4.5 m of the hood.

Perforated Ceiling 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 0.4 m/s. In some code jurisdictions, when conventional ceiling diffusers are used, only perforated diffusers are allowed in commercial kitchens. Perforated ceiling diffusers can be used near the hood, although a greater number of these diffusers may be required to reduce air velocities for a given supply rate. To help ensure proper hood performance, air from a perforated diffuser near the hood should not be directed toward the hood. If ceiling-supplied air must be directed toward a hood, air discharge velocity at the diffuser face should be selected so that the terminal velocity does not exceed 0.4 m/s at the edge of the hood capture area.

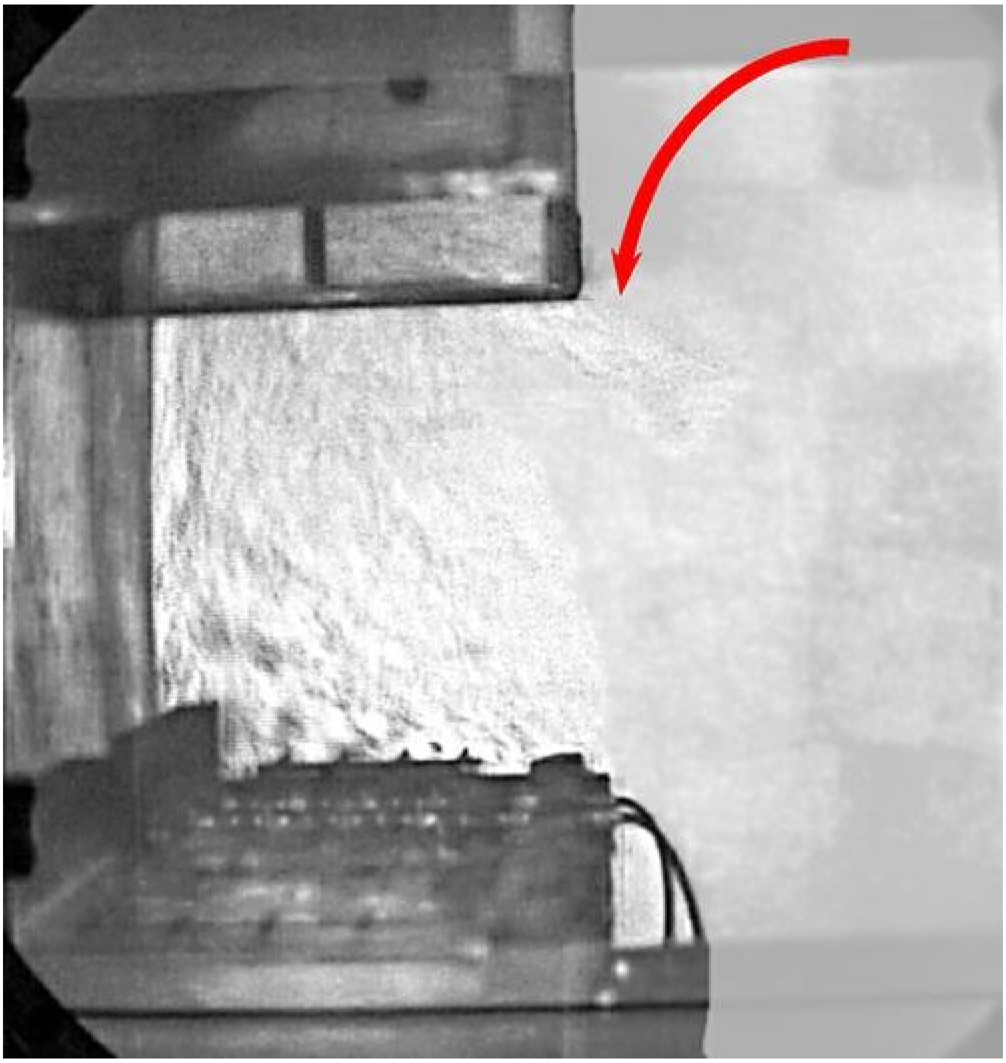


Figure 28. Schlieren Image Showing Thermal Plume Being Pulled Outside Hood by Air Discharged from Four-Way Diffuser (Brohard et al. 2003)

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 diffusers were used to determine the baseline for Brohard et al.'s (2003) replacement air study, because they 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 replacement air through displacement diffusers (Figure 29) may be an effective strategy for introducing replacement air. Adequate wall or floor space is required to accommodate displacement diffusers.

Other Factors That Influence Hood Performance.

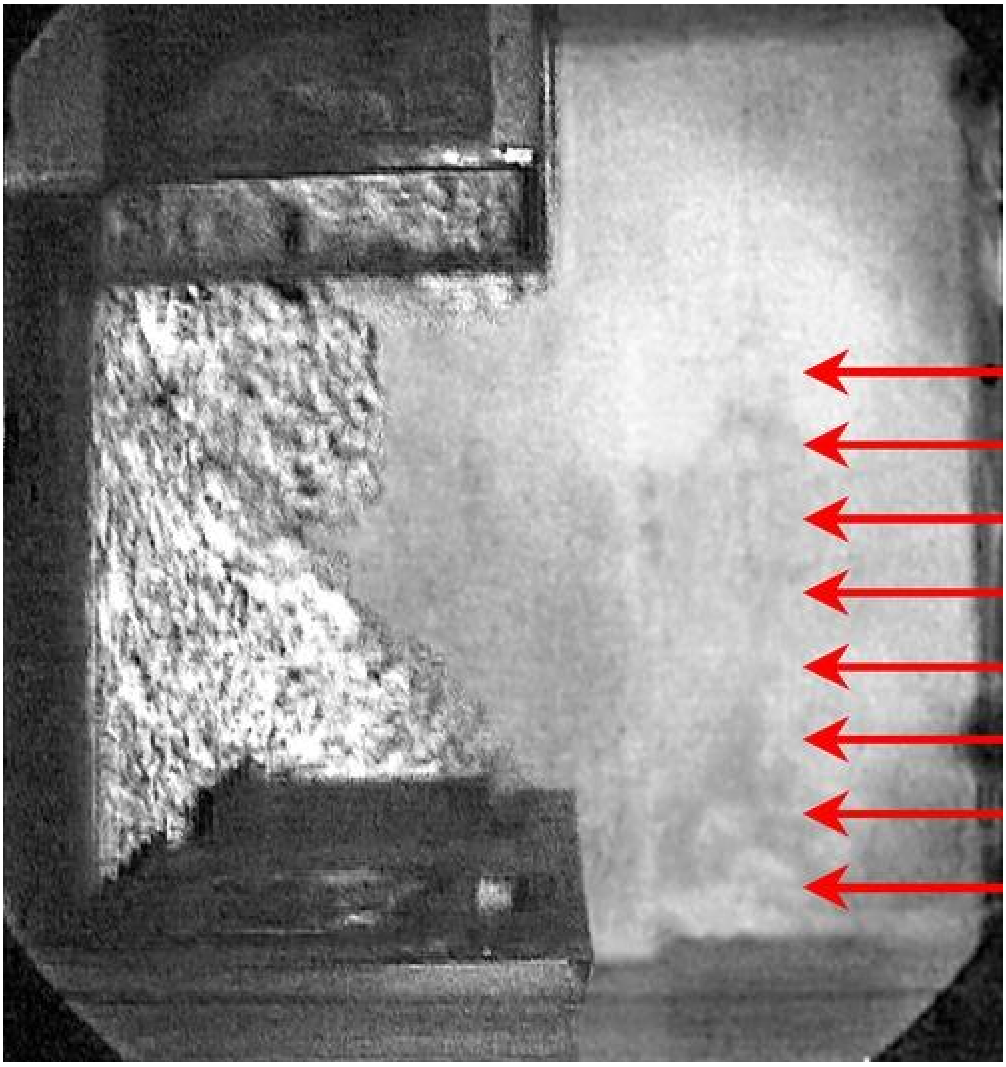


Figure 29. Schlieren Image Showing Plume Being Effectively Captured when Replacement Air Is Supplied at Low Velocity from Displacement Diffusers (Brohard et al. 2003)

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 (Brohard et al. 2003). 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.

Brohard et al. (2003) recommend reducing 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 or by distributing through multiple configurations. 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.

Effective introduction of replacement air (whether supplied through displacement ventilation diffusers, perforated diffusers located in the ceiling, and/or as transfer air from adjacent spaces) should be designed to limit velocities approaching the hood to less than 0.4 m/s.

Design Recommendations. The first step to reducing the replacement 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 may increase effectiveness and mitigate cross drafts, and is highly recommended where applicable. The next step is to take credit for outdoor air that must be supplied by the HVAC system to meet code requirements for space or occupant ventilating. Depending on the architectural layout, it may be practical to transfer most of this air to the kitchen. Assuming the transfer air is conditioned and properly introduced, it may enhance hood performance and improve the kitchen environment.

For more information, see the sections on Energy Considerations and Commercial Exhaust Hoods in this chapter.

1.9 HVAC SYSTEM DESIGN

As mentioned previously, one purpose of kitchen ventilation is to provide a comfortable environment for employees. Engineers who are used to designing HVAC loads for more traditional spaces (e.g., offices) may not realize how different the kitchen environment can be: kitchens require a much greater quantity of outdoor air as makeup, and have much higher internal loads (including sensible radiated heat gain from appliances underneath hoods, sensible and latent loads from unhooded equipment including warewashers, and sometimes outdoor air loads).

Table 12 Appliance Heat Gain Reference

Appliance Location	Fuel Source	Chapter 18, 2021 *ASHRAE Handbook—Fundamentals* Table Reference
Unhooded	All	5A and 5B
Hooded	Electric	5C
Hooded	Gas	5D
Hooded	Solid Fuel	5E
Hooded and unhooded dishwashers	All	5F

Hooded and Unhooded Appliance Loads

One of the challenges in performing cooling and heating load calculations for a kitchen is determining the space heat gains from the cooking appliances. Given that many of the largest cooking appliances include exhaust hoods to remove the smoke, grease, and heat, determining the heat gain can be challenge. There may also be a large number of smaller appliances that do not include exhaust hoods and which reject all their heat directly to the space.

Table 13 Heat Gain from Outdoor Air Infiltration

Type of Heat Gain	Equation	Chapter 18, 2021 *ASHRAE Handbook—Fundamentals* Equation Reference
Sensible	$q_s = 1.23Q_s\Delta t$	(9)
Latent	$q_l = 3010Q_s\Delta W$	(10)
Total (Sensible + Latent)	$q_t = 1.2Q_s\Delta t$	(7)

Notes: Q_s is flow in m^3/s, t is °C, W is kg water per kg air, h is kJ/kg, and q is heat gain in W. Δ is the difference between outdoor and space-neutral (room design) conditions.

Tables 5A to 5F in Chapter 18 of the 2017 *ASHRAE Handbook—Fundamentals* list typical equipment and the heat rejected into the kitchen. The data contained in these tables were updated as part of ASHRAE research project RP-1362 (Swierczyna et al. 2008). Table 12 summarizes which tables to use for what type of equipment.

For the majority of appliances, table heat gain values were determined during idle or standby condition: that is, the appliance was fully warmed up and in its ready-to-cook condition. (Typically, an appliance is in standby for as much as 70% of the day.) For appliances installed under an exhaust hood, the amount of heat emitted as radiation is listed, because this heat ends up heating nearby objects. For the appliances that are not installed under a hood because of their low energy consumption or lack of cooking effluent, the amount of both sensible and latent heat is listed, in addition to the radiation.

The greatest challenge with using these data is determining the diversity or usage factor of the appliances. It may be difficult to anticipate how often the appliance will be at full cooking or at some standby condition. Any assumptions made can be rendered incorrect by a change in kitchen throughput or sales. Determining the correct heat gain is an involved procedure that requires input from the entire kitchen design team.

Outdoor Air Loads

If the outdoor air is not conditioned to a space-neutral (or space design) condition, then the sensible and latent loads from this volume of air will impact the existing HVAC system at least to some extent because however the air is introduced into the kitchen some of it will enter the kitchen space especially if that air is hot and humid. Table 13 summarizes the relevant equations from Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals*. It is recommended that the load from at least 50% of the outdoor air brought into the kitchen to replace the exhaust air be used in the heat gain calculations.

The remaining heat gains from lighting, envelope, and people can be calculated following the procedure described in Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals*.

Thermal Comfort Research Results

ASHRAE research project RP-1469 (Stoops et al. 2013) conducted a large field survey on kitchens in the United States to identify how well engineers are satisfying design kitchen conditions. Researchers monitored space conditions in 105 kitchens during the summer. Figures 30 to 32 show the resulting temperatures in three areas of the restaurant (kitchen, food preparation, and warewashing) as a function of height above the floor.

Stoops et al. found that temperature increases with height above the floor: although floor-level temperatures ranged from approximately 24 to 28°C, at head level for staff temperatures ranged from 30 to 37°C. Higher temperatures at increasing heights can be partially attributed to radiated heat gain from the appliances underneath hood(s), but there is no question that the space conditions were not being met on average for most of the kitchens monitored in this study, even at the floor level. See Chapter 9 of the 2021 *ASHRAE Handbook—Fundamentals* for more information.

1.10 EXHAUST SYSTEMS

Exhaust systems remove effluent produced by appliances and cooking processes to provide 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 these 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 smoke of an appliance fire from the kitchen.

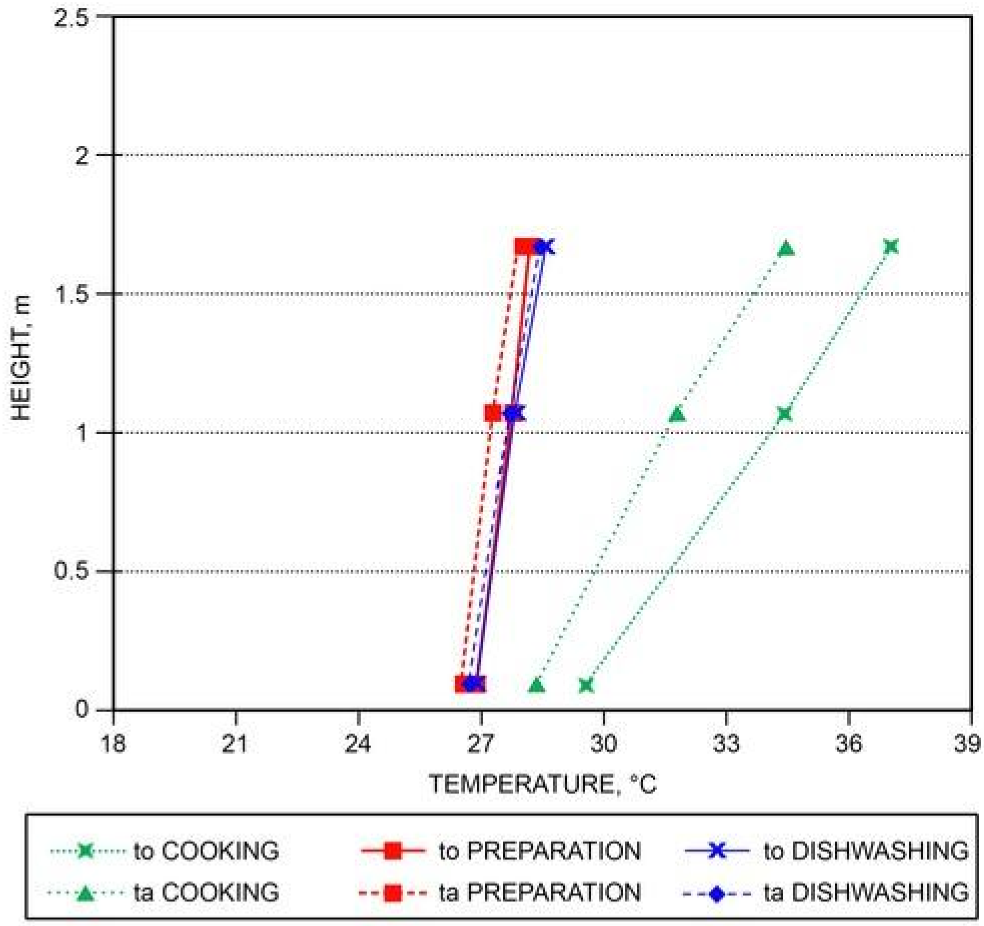


Figure 30. Summer Temperatures by Height and Kitchen Zone in Casual Kitchens

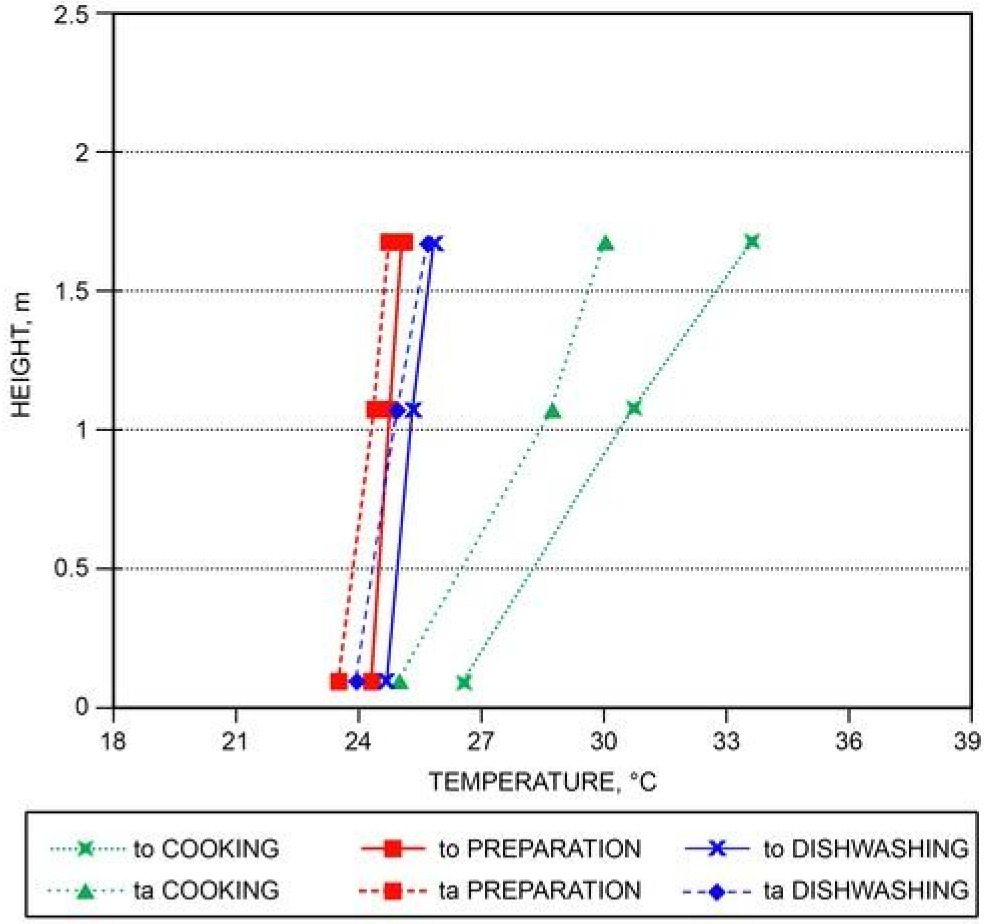


Figure 31. Summer Temperatures by Height and Kitchen Zone in Institutional Kitchens

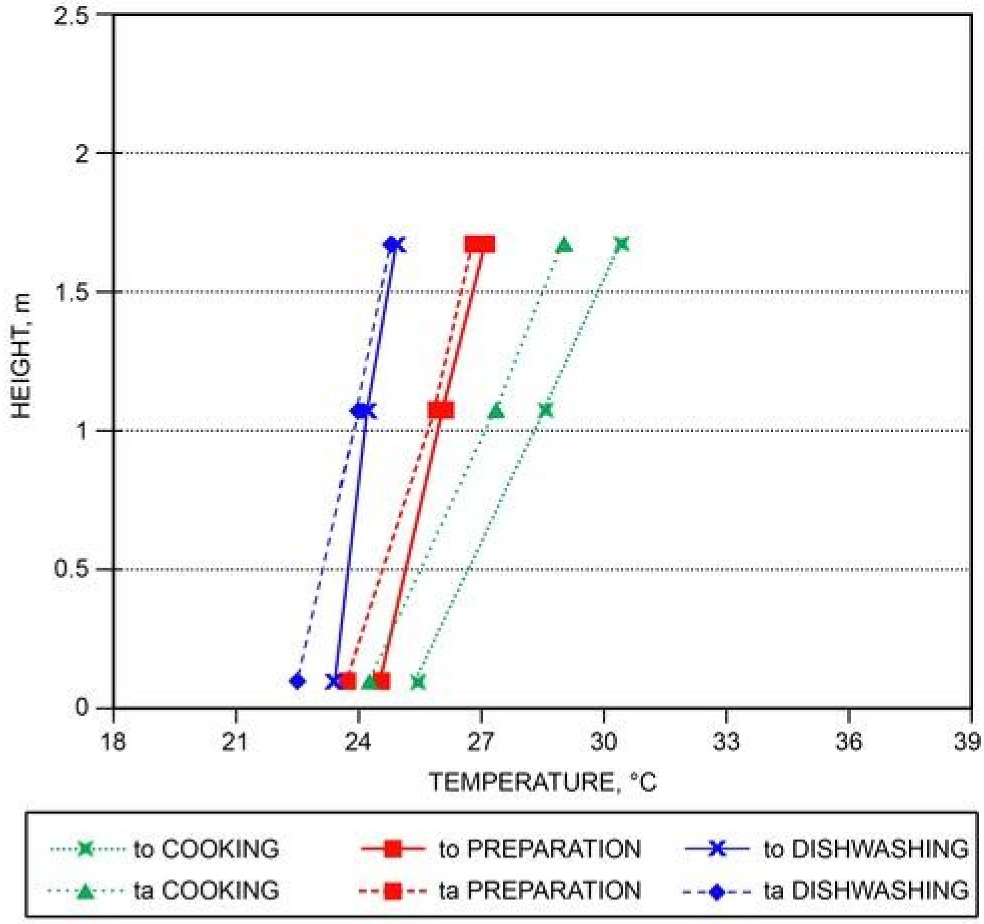


Figure 32. Summer Temperatures by Height and Kitchen Zone in Quick-Service Restaurant Kitchens

Duct Systems

Exhaust ducts convey exhaust air from the hood to the outdoors, along with any grease, smoke, VOCs, and odors that are not extracted from the airstream along the way. These ducts may also be used to exhaust smoke from a fire. To be effective, ducts 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 2018a), 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 had 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 and that grease deposition in ducts does not increase when duct velocity is lowered to 2.5 m/s, 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 because of spatial and cost constraints, current design practice for new single-speed systems generally is to design duct velocity between 7.6 and 9 m/s.

Ducts 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 1 h or 2 h fire resistance rating, and can be used in lieu of a fire-rated enclosure required in NFPA *Standard* 96 and IMC (ICC 2018a). See Chapter 19 in the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* and the Fire Safety section in this chapter for more information on grease duct construction.

1.11 EXHAUST FANS

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. See Chapter 21 in the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* and the Fire Safety section in this chapter for more information on fans.

The following types of exhaust fans are commonly used; 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 duct outlet (Figure 33), and discharge upward or outward from the roof or building. Aluminum upblast fans must be listed for the commercial kitchen exhaust application 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 motor, drive, and often a motor/drive weather cover (Figure 34). These fans are typically constructed of steel and roof-mounted. Where approved, centrifugal fans can be mounted indoors and ducted to discharge outdoors. 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.

- **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 35). Where approved, these fans can be located in the duct 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.

- **High-plume fan.** These fans may be used for kitchen applications when the requirements for a high exhaust plume are required (Figure 36). These fans generate a high nozzle exit velocity, which forces the exhaust plume to higher elevations and thus discharges smoke and grease laden vapors into the atmosphere. This fan is applicable when the intent is to prevent re-entraining smoke and grease-laden kitchen exhaust into the building makeup air system, or to discharge it over neighboring buildings or structures. When listed in accordance with UL *Standard* 762, a grease drain, grease collection device, and blower housing access panel are required. Because of the size and weight of these fans, the installation should be verified for structural integrity by a structural engineer. Items to be evaluated may include roof load, wind load, and seismic conditions.

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. See Chapter 46 of this volume for more information on exhaust discharge principles and considerations.
- 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 37 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.

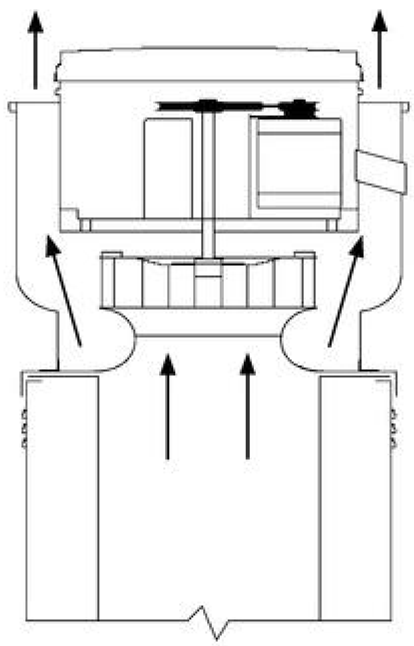


Figure 33. Power Roof Ventilator (Upblast Fan)

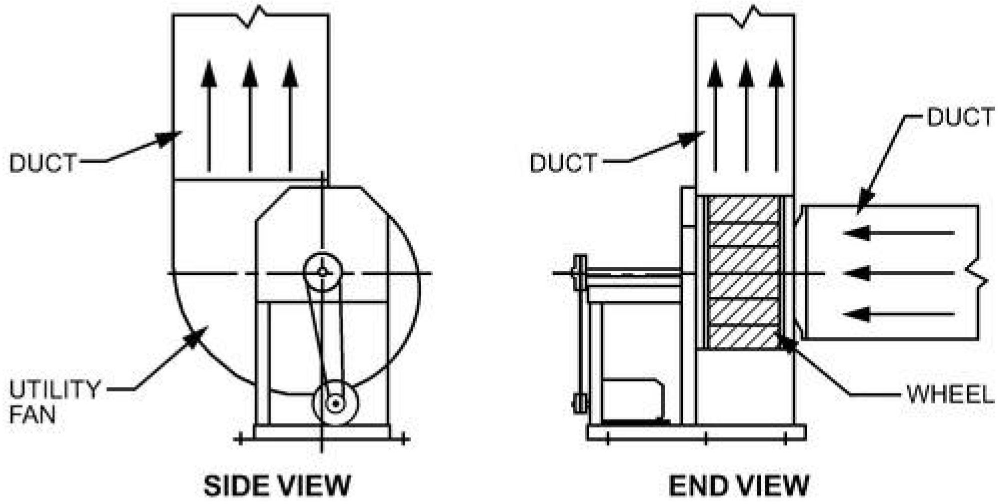


Figure 34. Centrifugal Fan (Utility Set)

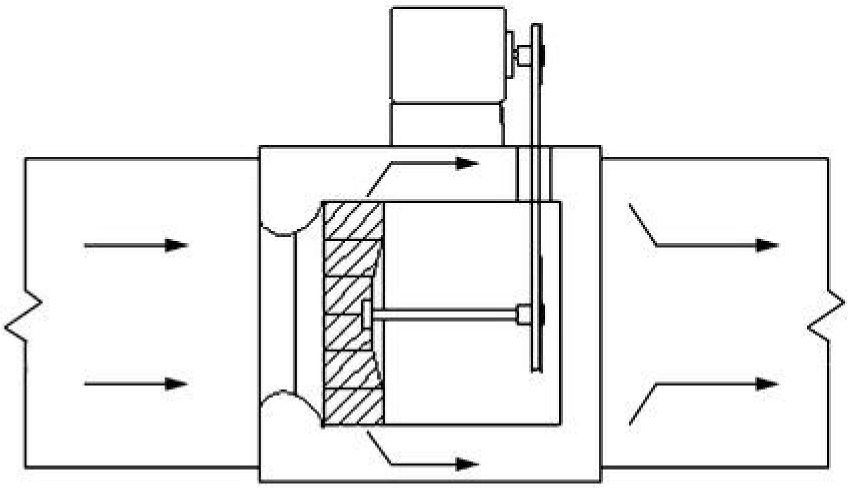


Figure 35. Tubular Centrifugal (Inline) Fan

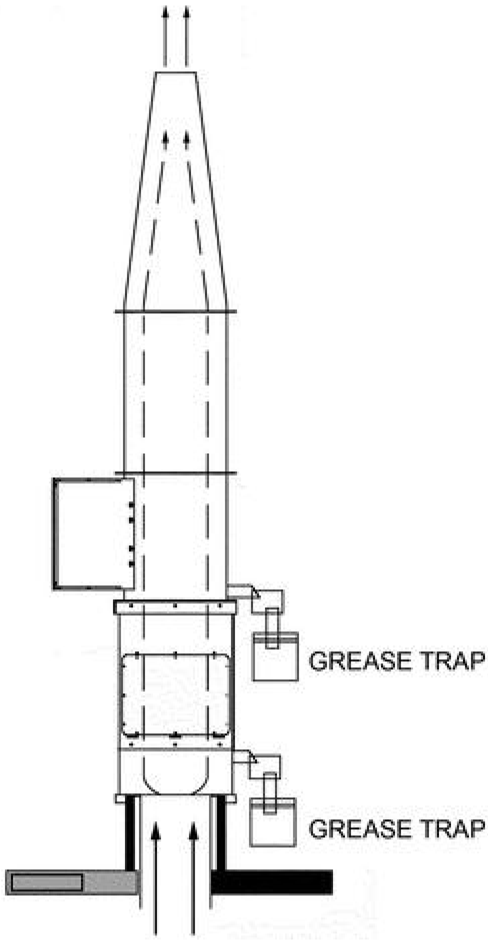


Figure 36. High-Plume Fan

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.

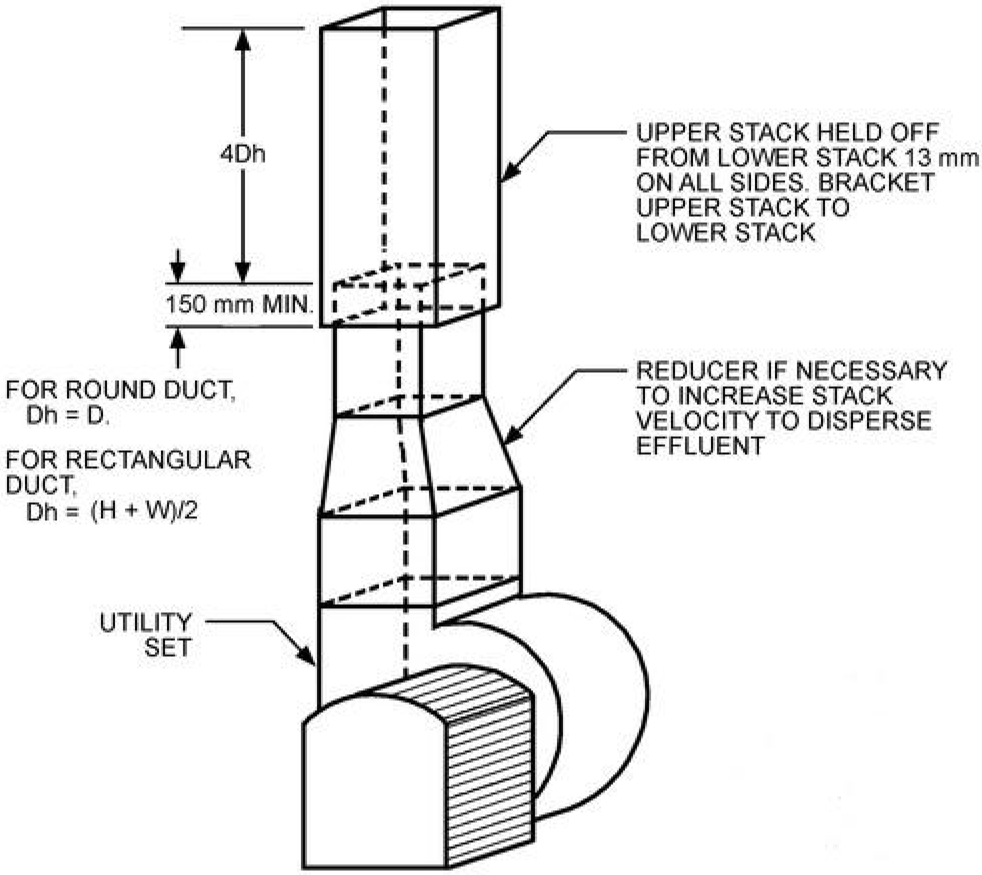


Figure 37. Rooftop Centrifugal Fan (Utility Set) with Vertical Discharge

Recirculating Systems. 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.

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 safety in locating the unit. These units are best for large, unconfined areas with a separate outdoor exhaust to keep the environment comfortable.

1.12 FIRE SAFETY

The combination of flammable grease vapor 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 commercial cooking equipment that may produce grease-laden vapors (i.e., a Type I exhaust system) must include a fire suppression system, as required by NFPA *Standard* 96 and the *International Mechanical Code* (IMC; ICC 2018a). The IMC further requires that the fire suppression system comply with the *International Building Code* (IBC; ICC 2018c) and the *International Fire Code* (IFC; ICC 2018d). By further reference, these codes and standards require that automatic fire suppression systems for Type I hoods must be listed to UL *Standard* 300.

Replacement air systems, air-conditioning systems serving a kitchen, and exhaust systems serving 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 safety starts with proper design, followed by proper operation and maintenance of the cooking equipment and the exhaust system, including frequent and thorough cleaning of grease deposits in the area of appliances, and exhaust filters, hoods, and ducts. After that, the three primary aspects of fire protection in a grease exhaust system are (1) to extinguish a fire quickly once it has started, (2) to prevent the spread of fire from or to the grease exhaust system, and (3) to prevent heat transfer to building components from a grease duct fire if the fire-extinguishing system fails. Additionally, UL *Standard* 300 requires that the fire suppression system not disperse burning grease outside the fire zone, and that, after a fire is suppressed by a fire suppression system, it must remain suppressed for at least 20 min.

Solid-Fuel Cooking. When solid-fuel cooking is used in commercial kitchens, fire risk is increased by the formation and deposition of combustible creosote in exhaust systems. Creosote is formed when unburnt vapors from solid-fuel combustion condense in exhaust systems. Creosote production is increased when moisture is present in solid-fuel combustion, such as when green or wet wood is burned, or when solid fuel is burned in the presence of fuel gas combustion products, one of which is water vapor. Chapter 14 of NFPA *Standard* 96 provides extensive requirements for solid-fuel cooking operations. Note that solid-fuel cooking appliances are referred to as "extra-heavy-duty cooking appliances" in the IMC and are defined as those using open-flame combustion of solid fuel at any time during the cooking process.

Fire Suppression Systems

NFPA *Standard* 96 requires that exhaust systems serving grease-producing equipment must include a fire-extinguishing system that protects the cooking equipment, hood interior, hood filters or grease extractors, ducts, and any other grease-removal devices in the system.

Actuation of any fire-extinguishing system must not depend on building electricity. If actuation relies on electricity, it must be supplied with standby power, usually in the form of battery backup.

Listed fire suppression systems must also automatically shut off all supplies of fuel and energy 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 an 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 the exhaust system is in a building with a fire alarm system, actuation of the fire-extinguishing system should send a signal to the fire alarm system. With solid-fuel cooking, there is no practical means of stopping combustion of the burning fuel, and consequently, detection, activation, and performance of fire suppression systems are especially important.

Dry and Wet Chemical Systems. Wet chemical and combinations of wet chemical and water fire-extinguishing systems have comprised the majority of fire suppression systems since the publication of UL *Standard* 300 in 1994 and its subsequent citation by codes and standards. Dry chemical systems were popular through the early 1990s, but their use declined because they do not meet the requirements of UL *Standard* 300 and must be replaced with UL *Standard* 300 listed systems. Wet chemical systems are covered in NFPA *Standard* 17A, and though obsolete since UL *Standard* 300 was published, dry chemical systems are covered in NFPA *Standard* 17. Both standards provide detailed application information.

Fire suppression systems are tested for their ability to extinguish fires in cooking operations in accordance with UL *Standard* 300. Wet chemical systems extinguish fires by reacting with fats and grease to **saponify**, or form a soapy foam layer, which prevents oxygen from reaching the burning 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, the fat can reignite.

Frying media commonly used today, which contain a high percentage of vegetable oils, have autoignition points of about 360 to 375°C when new. Contamination and deterioration through normal use lowers the autoignition point. In addition to the formation of a foam blanket instead of a thin layer of powder, another advantage of wet chemical systems over dry chemical systems is that the former cools the frying media, bringing it below the autoignition point more quickly. With solid-fuel cooking, the flash point of liquid creosote ranges from 74 to 92°C and the autoignition temperature for solid creosote ranges from 233 to 360°C. These temperatures suggest that creosote in ducts from solid-fuel cooking can be a greater fire hazard than grease alone.

For a wet 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 and pointing in the direction of effluent flow) to protect the grease duct.

Two types of nozzle arrangements are common for protecting appliances. Appliance specific coverage is provided by nozzles that are usually directed at the centers of individual appliances. Overlapping coverage is provided by a generally greater number of evenly spaced nozzles. Although overlapping coverage is slightly more expensive to install and maintain, this arrangement solves the common problem of appliances being periodically rearranged under hoods to meet operational needs.

The duct nozzle is rated to protect an unlimited length of duct, so additional nozzles are not required further downstream in the duct. Additional nozzles and piping in ducts would also make periodic duct cleaning more difficult.

Listed fire-extinguishing systems are available as pre-engineered (packaged) systems, installed by authorized exhaust hood manufacturers or local authorized fire suppression system distributors/dealers. In either case, required periodic maintenance of fire suppression systems is performed by local authorized fire suppression system distributors/dealers.

Chemical systems typically consist of one or more tanks of chemical agent, a propellant gas cartridge, piping to the suppression nozzles, fire detectors, and auxiliary equipment. Auxiliary equipment may include manual actuation ("pull") stations, gas shutoff valves (spring-loaded or solenoid-actuated), and auxiliary electric contacts.

Fire detection is required at the entrance to each duct (or ducts, in hoods with multiple duct takeoffs). The fire detectors are typically fusible links that melt at a set temperature associated with a fire, although electronic detection with battery back-up is also available.

Actuation of chemical suppression systems is typically mechanical, requiring no electric power, by means of a spring-loaded device that pierces the seal on a propellant canister. Fire detectors are typically interconnected with the system actuator by steel cables in tension, so that melting of any fusible links, in series configuration, releases the tension on the steel cables, causing the spring-loaded actuator to release the propellant and force suppressant through pipes and nozzles.

The total length of the steel cable and number of pulley elbows allowed in the detection system are limited. A manual pull station is typically connected to the system actuator by steel cable. If a mechanical gas shutoff valve is used, it is also typically 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, keep the related exhaust fan running, and/or send an alarm signal to the building fire alarm system. With electrically actuated fire suppression systems, detection is by electronic temperature sensors, and manual pulls are electric, in place of fusible links, cables, pipes, and pulleys.

Manual pull stations are generally required to be at least 3 m from the cooking appliance and in a path of egress. Some code 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 equipment, hoods, and 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 equipment, hoods, and exhaust systems is covered by NFPA *Standard* 13. NFPA *Standards* 25 and 96 cover 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.

One advantage of a sprinkler system is that it has virtually unlimited capacity, whereas chemical systems have limited chemical supplies. Where sprinklers are used in ducts, the duct 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.

Combination Systems. 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 devices, and/or ducts in the event of a fire, if listed to UL *Standard* 300. The water supply for these systems may be from the kitchen water supply if flow and pressure requirements are met. Examples include (1) an approved water-wash or water-mist system to protect the hood in combination with a listed wet chemical system to protect ducts and the cooking appliances (2) a listed chemical fire suppression system in the hood backed up by water sprinklers in the duct, or (3) a listed wet chemical system for appliances, with simultaneous use of a hood water-wash system, with foam-forming chemical injected into the water, for hood plenum and duct.

Hybrid Systems. Several types of hybrid systems have been developed to improve upon conventional fire suppression system designs. One type connects to the domestic water system and then discharges this water on the protected areas following initial activation and wet chemical agent discharge, but it retains fusible links for detection. A second type provides electronic detection in place of fusible links, cables, cable conduit, pulley elbows, and tees, though it retains conventional wet chemical fire suppressant. Another UL *Standard* 300 equivalent system (based on UL *Outline of Investigation* 199E) relies on the water supplied by the building's NFPA *Standard* 13 compliant sprinkler system. Suppression is handled by the activation of sprinklers and hybrid water/aqueous film-forming foam (AFFF) sprinklers directly over the fire location.

Electronic Systems. These systems include electronic detection, activation, monitoring, annunciation of issues with readiness for suppression, and battery back-up. Connection to building management systems or other networks is optionally available. Surfactant is added to the supplied water suppressant to improve water coating of surfaces. Newer systems can also combine cold water and surfactant fire suppression with daily hood and lower duct cleaning by hot water and surfactant. With electronic detection, detectors can be mounted high in ducts, using listed duct penetrations, to better detect fires that autoignite in ducts, such as from solid-fuel cooking and related creosote deposits.

Multiple-Hood Systems. All hoods connected to a multiple-hood exhaust system must usually meet several requirements. In the IMC (ICC 2018a), for example, the hoods must be on the same floor of the building, all interconnected hoods must be in the same room or in adjoining rooms, interconnecting ducts must not penetrate assemblies required to be fire-resistance rated, and the grease duct system must not serve solid-fuel-fired appliances.

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 duct system. Of course, the first line of protection for the ducts is keeping them clean. Especially in a multiple-tenant system, a single entity must assume responsibility for cleaning the common duct frequently.

Each hood must have its own fire-extinguishing system to protect the hood and cooking surface. A single system might 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 duct must have its own fire extinguishing 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 mentioned earlier, actuation of the fire-extinguishing system protecting any hood must shut off fuel or power to all cooking equipment under that hood, but fuel shutoff is not possible with solid-fuel cooking. 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 every portion of it protected by the activated system, even if there is 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 prevents a fire in the common duct from causing discharge of fire suppressant under an unaffected hood and it 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 started in the 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 through the exhaust system. This protection has three main aspects: (1) maintaining clearance from the duct to other portions of the building, (2) either enclosing the duct in a fire-resistance-rated enclosure, or wrapping the duct with a listed fire-rated product, and (3) designing, constructing, and testing to ensure integrity of the duct before and during a fire. These methods are sometimes addressed by a listed insulated grease duct system that incorporates an integral fire resistance.

Clearance to Combustibles. A grease fire can generate gas temperatures of 1100°C or greater in the exhaust hood and duct. In such a grease fire, heat radiating from the hot surface can ignite combustible materials near the hood or duct. Additionally, if the hood or duct is not fully welded and liquidtight as required by codes and standards, grease liquid or vapor leaking from the hood or duct can ignite and spread fire to nearby combustible structure. Most codes require a minimum clearance of 460 mm from the hood and grease 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 with large volumes of grease in larger ducts.

Several methods to protect combustible materials from the radiant heat of a grease fire and allow reduced clearance to combustibles are described in NFPA *Standard* 96 and the IMC (ICC 2018a). Based on testing and listing of grease ducts provided with integral insulation or wrapped with insulation, NFPA *Standard* 96 and other codes now allow listed insulation to be applied to the duct or a listed factory-built grease duct with integral insulation. For hoods, the clearance can be reduced as prescribed.

Listed grease ducts, typically with insulation between double walls or on the outside of single-wall ducts, may be installed with reduced clearance to combustibles in accordance with locally adopted codes and standards, if installed per manufacturers' instructions, which should include specific information regarding the listing. Listed grease ducts are tested and evaluated in accordance with UL *Standard* 1978.

NFPA *Standard* 96 requires a minimum clearance of 75 mm to "limited combustible" materials (e.g., gypsum wallboard on metal studs). The IMC (ICC 2018a) allows reduced clearance of ducts to 75 mm in proximity to noncombustibles on noncombustible structure, such as gypsum wallboard on metal studs. Clearance reduction is also available for hoods, but may differ by local code, so local codes and standards should be consulted accordingly.

Note that clearance-to-combustible issues are often seen in inspections of restaurant sites after grease fires. Many instances of inappropriate clearance reduction have been seen in which gypsum wallboard was mistakenly applied to wood studs and joists. In many of these cases, surrounding structure was ignited by heat from a grease fire, in spite of the gypsum wallboard barrier. The issue here is autoignition of the combustible material behind the gypsum wallboard from the high heat of the grease fire, even in cases where the gypsum wallboard layer is intact after the fire. Note that in some codes and standards, gypsum board is considered to be a combustible or limited-combustible material.

A simple means of complying with most building codes and standards' clearance requirements is the specification and installation of metal beams, joists, studs, and trusses within 457 mm of appliances, hoods, and ducts.

Enclosures. Normally, when a HVAC 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 cannot be installed in a grease duct unless specifically approved for such use, there must be an alternative means of maintaining the integrity of rated walls or floors. Therefore, grease 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 the IMC (ICC 2018a) require a minimum 150 mm clearance and that the shaft be vented to the outdoors. 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 use fire barrier insulation and provide integral fire-rated resistance, 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 accordance with the manufacturer's installation instructions.

Some insulation materials are listed to serve as a fire-resistance-rated enclosure for a grease duct when used to cover a duct. These insulations are tested and listed in accordance with ASTM *Standard* E2336. These listed insulations must be applied in accordance with the manufacturer installation instruction.

Insulation materials that have not been specifically tested and approved for use as fire protection for grease 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 ducts because of the high temperatures that may be encountered in a grease fire.

Duct Integrity. Ducts must retain integrity and stability during a grease fire so that the fire does not spread through unintended openings (poor welds or duct collapse). Factory-built stainless steel ducts are tested and listed to UL *Standards* 1978 and 2221 and are often dual listed to other high-temperature related all-fuel chimney standards (UL *Standards* 103 and 2561). A listed duct system is recommended for exhaust systems that are four stories in height or greater. Specification of listed ducts is recommended for all exhaust systems serving solid-fuel cooking. The model codes require testing for all duct joint/seam leakage, though for listed ducts, this testing is only required for duct joints assembled in the field.

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 allowed at any point in an exhaust system except where specifically listed for 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 hood 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 fusible link may become coated with grease if not properly maintained, which may impede damper operation. On the other hand, without the fire-actuated damper, the exhaust fan draws smoke and fire away from the hood. Although this cannot be expected to remove all smoke from the kitchen during 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 exhaust system 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 replacement air flow rates exceed 940 L/s, the replacement air supply to the kitchen might be required by some codes and standards 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 (internal) replacement air plenum such as with short-circuit hoods, a fire-actuated damper must be installed in the replacement air plenum to prevent a fire in the hood from entering the replacement air duct. NFPA *Standard* 96 details the instances where fire-actuated dampers are required in a hood replacement air plenum.

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 exhaust system or of the fire-extinguishing system. Listed fire-extinguishing systems protecting ducts are tested both with and without airflow, and exhaust airflow is not necessary for proper operation.

Control Systems. The IMC (ICC 2018a) requires that Type I (grease and smoke) hoods be designed and installed to automatically activate related exhaust fans whenever cooking operations occur.

1.13 SYSTEM COMMISSIONING AND AIR BALANCING

ANSI/ASHRAE/IES *Standard* 202 defines commissioning as "a quality-focused process for enhancing delivery of a project. The process focuses upon verifying and documenting that all of the commissioned systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the owner's project requirements."

For commercial kitchen ventilation (CKV), commissioning may involve validation of system components that are designed, supplied, and/or installed by multiple design professionals, vendors and building trades. This chapter's sections on Commissioning and Ventilation Design include steps that may be used to develop the owner's project requirements (OPR), including system design and installation.

It is not unusual for CKV systems to be treated as independent building systems, even though these systems can affect the safety and IEQ (including comfort and odor control) of the entire facility. Some locations may limit the effects the CKV system is allowed to have on the outdoor environment surrounding the facility. Given the CKV system's potential impacts, it is critical the OPR identifies responsibilities for system performance and its impacts on the facility and its environments. Refer to the System Integration and Design section of this chapter for more information.

Air Balancing

Kuehn (2010) demonstrated that a high degree of correction is required to achieve accurate airflow measurements with many of the instruments commonly used in the field to balance hood systems. Because of the level of correction required, hot-wire anemometers are not recommended. Therefore, balancing is best performed when the manufacturers of all system components provide a certified reference method of measuring the airflow of their equipment, rather than depending on generic measurements of duct flows or other forms of measurement in the field, which, again, can be erroneous. 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.

Basic tools for balancing include the following:

- Volumetric flow hood
- Rotating vane anemometer
- Velocity grid
- Pitot tube/anemometers
- Manometer/pressure meter
- Voltage/amperage meter(s)
- Tachometer

Using instruments with current calibration certification or new instruments is recommended.The general steps for air balancing in restaurants are as follows:

1. Verify all exhaust and HVAC equipment is installed correctly and operating correctly, including (but not limited to) verifying that exhaust ducts are fully welded and inspection doors are in place, HVAC and supply ducts are complete and sealed, fans are rotating the correct direction, all exhaust hood grease filters are installed and properly sized, and thermostats are set up correctly and set to on or occupied mode.
2. Tabulated results of measurements should be kept and used to create a balance chart to show the building’s net exfiltration or infiltration.
3. Exhaust hoods should be set to their proper flow rates, with supply and exhaust fans on.
4. 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 outdoor airflow rate. Then, correct outdoor 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 outdoor air. Where outdoor 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. See Chapter 39 for general HVAC testing, adjusting, and balancing information.
5. Next, outdoor air should be set with all fans (exhaust and supply) operating. Pressure difference between indoors and outdoors should be checked to confirm that (1) nonkitchen zones of the building are at a positive pressure compared to outdoors and (2) kitchen-zone pressure is negative compared to the surrounding zones, and positive or neutral compared to outdoors.
6. For applications with DCKV systems, proper capture and containment, as well as differential pressures between zones and atmosphere, should be confirmed at minimum and at maximum flow rates. 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.

System Tests

Cooking Exhaust Duct Leakage. ASHRAE *Standard* 154 outlines methods of test for exhaust system duct leakage. In most installations, the hood, exhaust fans, and replacement air equipment will be listed and labeled for its intended use. Exhaust duct systems may be field fabricated or listed factory-built systems. Either system requires joining sections in the field and may include field-installed cleanouts and inspections ports. It is critical to the fire safety of the facility and the performance of the CKV system that these duct systems be tested to assure they are properly installed. See

Chapter 19 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* for information on HVAC duct construction and leakage criteria.

Fire Suppression. Like the duct system, the hood fire suppression system requires some field work to complete the system installation. Typically, the local AHJ requires an operating test of the installed suppression system. Test requirements vary. If the local AHJ does not require such a performance test of the completed system, the OPR should specify that such a test be conducted.

DCKV. When a DCKV system is installed to control the CKV systems, a system test should be conducted. This test should include the full range of the DCKV modulation, including the effects on exhaust and replacement air system performance throughout that full range. Examples include, at DCKV modulation extremes, (1) heating/cooling performance, (2) effective airflow distribution, and (3) maintaining proper pressure balance between the kitchen, adjacent spaces, and atmosphere.

Building Automation System. The CKV system for controlling the temperature and proper pressurization of food preparation spaces and zones must be tested to ensure it operates properly as designed. If other spaces and zones outside of the food preparation zone provide replacement air for the CKV system, then they must also be tested to ensure their proper operation.

Performance Test

After initial airflows are verified to be at design values and the building is balanced, a performance evaluation of all exhaust hoods should be performed to verify capture and containment (C&C) at the design conditions. ASHRAE *Standard* 154 outlines performance test methods.

Conduct Type I and II hood field testing with all appliances under the hood at operating temperatures, with all the hoods operating at design airflows, with all sources providing replacement air for the hood operating at design airflows, and with all sources of recirculated air in the space operating at design airflows. C&C is verified visually by observing smoke or steam produced by actual cooking or dishwashing operation.

Simulating devices such as smoke candles or smoke puffers are good for detecting air currents moving inward at the lower edge of the hood, but generally do not produce enough smoke to simulate full-load cooking operation. Note that smoke bombs typically create new effluent from a point source, and though they may create a volume of effluent that is equivalent to that of cooking effluent, their use to determine whether actual cooking effluent would be captured by the hood is not always reliable. Actual cooking at the full load or at the highest production rate is the most reliable method of generating smoke. Note that many health department rules for new facilities typically do not allow food to be brought into the facility until all safety and health inspections are complete and approved. Actual cooking may require special arrangements with the AHJ and should be considered in lieu of simulation methods, or as a final method to verify capture as part of the commissioning process for a hood’s ventilation system.

Hood systems with DCKV should be tested in auto mode to verify that the system responds appropriately to the changes in cooking operation. Begin with the cooking appliances off and confirm that the system is at minimum airflow. Then, turn cooking appliance on and verify that the airflow increases with increasing temperature. Once the appliances reach cooking temperature, generate smoke through actual cooking and verify C&C or simulation, as described previously. The evaluation should be performed at light, medium, and heavy-load conditions to verify C&C.

If hoods fail the performance test, examine the systems and correct any capture problems. Close attention should be given to the design considerations and guidelines in this chapter to correct any performance problems.

Follow-Up: Records

1. A punch list of any remaining issues encountered during installation, air balancing, or performance testing should be recorded and submitted to the facility management and any affected contractors so that these items can be corrected.

2. 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 systems, replacement air systems, HVAC supply and return serving the hood area, and individual diffuser and/or grille airflows must also be completed. If the unit includes a fan, records must include fan or unit model(s) and size(s), fan wheel and motor rpm, and fan motor amp draw. These records should be kept by the food service facility for future reference.

3. For new facilities, after two or three days in operation, all belts in the system should be checked and readjusted to correct new belt run-in wear. This examination should take place no later than a week after initial operation, and before the facility opens if possible. Obviously, direct-drive systems do not require this inspection or replacement.

4. Once the facility is operational, check performance of the ventilation system to verify that the design is adequate for actual cooking operation, particularly at maximum cooking and at outdoor environmental extremes. Any necessary changes should be made, and all the records should be updated to show the changes.

5. Rechecking the air balance should not be necessary more than once every two years. If there are any changes, such as adding a new type of cooking equipment or deleting exhaust connections, the system should be modified, rebalanced, and retested accordingly. Recommend a rebalance/retest whenever components of the kitchen ventilation and HVAC systems are replaced/modified (e.g., when an exhaust or supply fan is replaced or when supply/return air outlets are added or relocated within the kitchen). The system should also be rebalanced/retested whenever a cooking appliance is relocated or replaced with an appliance of different function. For example, if a fryer was replaced with a broiler, the ventilation would have to be rebalanced and retested for the broiler. Modifications should be recorded, added to owner's records, and marked on affected equipment.
6. All final operational measurements and recording shall be retained as a reference for future energy audit field surveys.

Refer to section 1.14, Recommissioning for recommended CKV system recomissioning frequencies.

1.14 OPERATIONS AND MAINTENANCE

Sustainability Impact

Proper operation and maintenance of all kitchen ventilation systems is an often overlooked requirement, but is one of the most critical, especially given the large amount of resources used in CKV operation. Typically, most attention is focused on the production of food, which is the primary role of any commercial kitchen. Given the kitchen ventilation system's role in providing replacement air, heating and cooling, and cooking effluent extraction, ensuring it is properly operated and maintained is critical for minimizing both overall system energy use and any environmental impacts both inside and outside the restaurant caused by effluent produced during cooking. Systems that are not operated or maintained correctly are likely to consume excessive energy, may create uncomfortable conditions in the kitchen area, may create an environmentally hazardous condition in the kitchen (e.g., hoods that do not capture and contain cooking effluent), and may affect outdoor environmental conditions (e.g., when pollution control devices are not operating properly). Additionally, given the fire hazards associated with commercial cooking, improper operation and maintenance of a kitchen's ventilation system(s) can even create a life safety hazard. Maintaining a proper air balance is part of a kitchen ventilation system's necessary maintenance. See Chapter 40 for more information on the costs associated with building operations and maintenance.

Finally, as part of any total commissioning process, the impact of operations and maintenance must be taken into account, especially ensuring that any related tasks can be performed with minimal disruption to food service production. If the system's proper operations and associated maintenance are not easily performed, they will most likely be deferred or not performed at all.

Operation

All components of the kitchen's ventilation system, and in some instances the entire building's 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 ventilation system's design intent should be fully understood by the owners and operators, so that any deviations in operation can be noted and corrected. *This is especially critical when a DCKV system is used.* 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, maximizes the system's energy efficiency, and extends 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. Any maintenance should include a check of the building automation system (BAS) as it relates to the kitchen ventilation system to ensure it is operating per its original design.

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 4) 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 (e.g., Hoods)

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. High-efficiency grease extractors may require frequent cleanings during each shift. 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 if the combustibles' depth is greater than 2 mm in any part of the system, and by a method that leaves no more than a 0.05 mm depth deposit of combustibles. 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 only be disarmed by properly trained and qualified service personnel 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 check local codes because stricter requirements are sometimes 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.

Recommissioning

Proper preventative maintenance and periodic recommissioning and rebalancing is necessary for achieving the designed performance and life cycle of the CKV systems. The following recommendations are based on field experience:

- Recommission and rebalance CKV systems, at minimum, every five years.
- Recommission and rebalance CKV systems any time changes are made to the CKV equipment, related HVAC equipment, or to the cooking operations. For example, replacing exhaust or makeup fans, relocating supply or return air grilles, relocating cooking equipment, or replacing cooking equipment with equipment of a different function (e.g., a fryer replaced with a broiler). These new or altered systems need to be tested, balanced, and commissioned for the new usage.
- Recommission and rebalance CKV systems any time performance issues arise, such as smoke or heat loss from the kitchen hoods, abnormal space temperatures, high-velocity air currents at pass-through windows, condensation, negative building pressure, etc.
- Capture and containment verification check of kitchen exhaust hoods every year.
- Verify proper outside air quantities every two years.
- Performance verification check of all control systems related to the CKV system every year.

Preventative maintenance is key to maintaining designed performance and life cycle cost of a CKV system. As grease builds up inside the kitchen exhaust ductwork, so does the static pressure and the corresponding potential for a fire. Depending on the available static that the exhaust fan was selected, pressure loss increase could become more than the fan can handle, which would reduce the required airflow rate, creating poor smoke and heat capture as well as overloading the fan.

2. RESIDENTIAL KITCHEN VENTILATION

Although commercial and residential cooking processes can be similar, their ventilation requirements and procedures are different. Differences include exhaust airflow rate and hood 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 3), are 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 required 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 relative to surrounding spaces. By-products of cooking and natural gas burning processes, such as $PM_{2.5}$, CO_2, CO, and HCHO (formaldehyde), can negatively impact indoor air quality and respiratory health and should be considered during system design. A residence also has a much lower outdoor air ventilation rate, making the presence of any 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. Active research is being conducted to better understand the health risks that can be caused by the effluent produced from residential cooking, and the best means for mitigating those risks.

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.

2.1 EXHAUST SYSTEMS

Hoods and Other Ventilation Equipment

Wall-mounted, conventional range hoods ventilate most residential kitchens. 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, there are high-end residential exhaust hood manufacturers that provide 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

Safety requirements covering residential cooking area fans are contained in UL *Standard* 507. These fans and accessories are intended for use in conjunction with residential gas and electric cooking appliances only, and are investigated to determine the effects of increased air temperature and grease on electrical components. The filters provided as a part of the fan are also checked for flammability and smoke propagation. Products include hood fans intended to mount directly over (but not directly on) ranges, separate hoods provided with lights or other wiring and intended for use over ranges in conjunction with a remote blower, downdraft fans, and oven ventilators for use over wall-insert ovens. Fans intended for mounting directly on cooking equipment are investigated in conjunction with the cooking appliances, and are typically listed as part of the accessory to the cooking appliance. Fans installed in close proximity to a stove, range, or oven where fumes, grease-laden air, or the like may be present and intended to discharge air away from the cooking area should be installed to discharge air to the exterior of the building and not into concealed walls or ceiling spaces or into the attic. Ductless fans intended for use in cooking areas are not required to discharge air to the building exterior.

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 520 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.

Recommended minimum exhaust airflow rates vary among model codes. 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. ASHRAE *Standard* 90.2 requires a minimum exhaust rate of 47 L/s intermittent. IMC (ICC 2018a) requires a minimum exhaust rate of 47 L/s intermittent or 12 L/s continuous. 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.

In some instances, commercial cooking equipment is used in residential applications. In these instances, special care should be taken for using adequate Type I or Type II exhaust hoods, ducting, and air flow requirements that are more in line with commercial or mechanical codes, because residential codes do not address this scenario.

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 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. IMC (ICC 2018a) requires that exhaust hood systems capable of exhausting 189 L/s or greater be provided with makeup air at a rate equal to the exhaust rate. Additionally, the makeup air system is to be equipped with a means of closure and operated simultaneously with the exhaust system to ensure proper building pressurization.

High-Rise Systems

Multistory structures with a common exhaust system serving multiple kitchen areas have additional requirements, as detailed in the Domestic Kitchen Exhaust Equipment section of the IMC. Typically, each resident's hood fan discharges into a common exhaust riser duct, at the top of which is a large fan rated for kitchen exhaust duty. A diversity factor is included in the sizing of this duct and fan, because not all of the kitchen hoods will operate simultaneously. Static pressure sensor(s) located in the duct riser controls the speed of this fan so that a small but continuous negative duct pressure is maintained regardless of the number of hoods being operated. Makeup air for this kitchen exhaust is typically provided by a central makeup air unit that serves the entire building's makeup air needs, including those for other exhausts (e.g., toilets, clothes dryers). Commissioning of these makeup and exhaust air systems is required to ensure each area has sufficient exhaust airflow to remove convective heat and effluent generated by the cooking process.

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, almost always the result of unattended cooking, continue to occur. There is no industry-accepted standard of design in residential fire-extinguishing equipment. When extinguishing systems are installed over residential range tops, the system should comply with UL *Standard* 300A.

Maintenance

All 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.

3. RESEARCH

RESEARCH OVERVIEW

ASHRAE Technical Committee TC 5.10, Kitchen Ventilation, has been active in research related to kitchen ventilation, as shown in Table 14. This research has tended to focus on answering questions related to field-related issues, such as how to measure exhaust airflow rates for hood and replacement air systems (RP-623 and RP-1376) and how much grease is produced by cooking appliances (RP-745 and RP-1375), and a current project is evaluating the grease and heat gain from unhooded countertop cooking appliances (RP-1631). Some of the research focused on design aspects of kitchen ventilation systems, from optimizing exhaust hood performance (RP-1202 and RP-1480), to evaluating the grease removal efficiency of filtering devices (RP-851 and RP-1151) and reducing the velocity of airflow in the exhaust ductwork (RP-1033). Other projects evaluated relationships between appliances and ventilation systems and the HVAC system in the space (RP-1362).

Table 14 Summary of TC 5.10 Research Projects

Year(s)	ASHRAE Project	Title
1993 to 1994	RP-623	A Field Test Method for Determining Exhaust Rates in Grease Hoods for Commercial Kitchens (Gordon and Parvin 1994)

1996 to 1997	RP-851	Determining the Efficiency of Grease-Removal Devices in Commercial Kitchen Applications (Schrock 1998)
1998 to 1999	RP-745	Identification and Characterization of Effluents from Various Cooking Appliances and Processes as Related to Optimum Design of Kitchen Ventilation Systems (Gerstler et al. 1998)
2000 to 2001	RP-1033	Effects of Air Velocity on Grease Deposition in Exhaust Ductwork (Kuehn 2000)
2001 to 2003	RP-1151	Development of a Draft Method of Test for Determining Grease Removal Efficiencies (Welch 2004)
2003 to 2005	RP-1202	Effect of Appliance Diversity and Position on Commercial Kitchen Hood Performance (Swierczyna et al. 2006)
2007 to 2008	RP-1375	Characterization of Effluents from Additional Cooking Appliances (Kuehn 2008)
2008 to 2009	RP-1362	Revised Heat Gain and Capture and Containment Exhaust Rates from Typical Commercial Cooking Appliances (Swierczyna 2008)
2008 to 2010	RP-1376	Method of Test to Evaluate Field Performance of Commercial Kitchen Ventilation Systems (Kuehn 2010)
2008 to 2009	RP-1480	Island Hood Energy Consumption and Energy Reduction Strategies (Swierczyna et al. 2010)
2010 to 2013	RP-1469	Thermal Comfort in Commercial Kitchens (Stoops 2013)
2013 to 2015	RP-1631	Countertop Commercial Appliance Emissions (Zhang 2015)
2017 to 2020	RP-1614	Developing a Test Method to Determine the Effectiveness of UVC Systems on Commercial Cooking Effluent

A comprehensive study has been conducted using both field measurements and field surveys regarding thermal comfort in commercial kitchens (RP-1469), and a research project (RP-1614) developed a method of test to determine the effectiveness of UVC systems installed in commercial kitchen ventilation systems. Additionally, this project evaluated UVC systems effectiveness on cooking effluent for a few select food products and their associated cooking processes.

BENEFITS TO THE HVAC INDUSTRY

Many of the research projects that TC 5.10 sponsored have affected energy use and sustainability in the food service industry. RP-1033 data showed that grease deposition on the walls of duct actually decreased when the duct velocity was lowered from 7.6 m/s to 2.5 m/s. These data allowed both NFPA *Standard* 96 and the International Mechanical Code (ICC 2009) to allow lower duct velocities. These changes allow demand-controlled ventilation systems (in which airflow is lowered during noncooking periods of the day) to be used across the United States to achieve significant energy savings.

The two projects related to hood performance (RP-1202 and RP-1480) not only evaluated how wall canopy and island hoods perform with various appliances, but also evaluated methods of reducing the exhaust airflows required for the hoods to capture the cooking effluent more efficiently. These include items such as optimizing the appliance position underneath the hoods, installing side panels, and designing hoods to use larger overhangs if possible. If exhaust air is reduced, this also generally reduces how much conditioned air needs to be brought back into the space to replace the air that is exhausted, leading to large energy savings in restaurants. RP-1362 measured the heat gain from appliances underneath hoods, and these data can be used to more accurately size the HVAC equipment needed to condition the kitchen space.

Earlier projects related to grease emissions (RP-851, RP-745, and RP-1151) were used to help develop ASTM *Standard* F2519. Data from these research projects, along with *Standard* F2519 and data from RP-1375, revolutionized the kitchen ventilation industry with regard to how mechanical filters actually perform in the field and the ASTM *Standard* provides a framework for making more efficient filters that help reduce the amount of grease built up in ductwork, on exhaust fans, and on the roof of buildings.

Another project (RP-1631) evaluated the appliance emissions and heat gain to space from countertop commercial cooking appliances to help determine whether these processes require a ventilation hood or can be vented to the space

RP-623 and RP-1376 both examined how to accurately measure the exhaust and replacement air in food service establishments. By being able to more accurately measure the airflows, restaurants can be properly balanced to the design conditions so that excess energy is not consumed. RP-1614 provided clarity for determining UVC systems effectiveness so that it can be properly applied as a cooking effluent control approach.

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