Halton

ENGINEERING AND DESIGN GUIDE FOR COMMERCIAL KITCHENS

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1 Design Fundamentals

1.1 Commercial Kitchen Ventilation Systems

The commercial kitchen is a unique space where many different HVAC applications are taking place within a single environment. Exhaust, supply, transfer, refrigeration, building pressurization and air conditioning all must be considered in the design of most commercial kitchens.

It is obvious that the main activity in the commercial kitchen is food preparation. This activity generates heat and effluent that must be captured and exhausted from the space in order to control odor and thermal comfort. The amount of supply air into a space, both tempered and un-tempered coupled with transfer air from surrounding spaces should match the exhaust airflow to maintain the airflow balance of a building. So, if the systems design all stems from the amount of air to be exhausted, it stands to reason that the exhaust air quantity is critical to good system operation, providing thermal comfort and productivity of workers.

Let's explore this concept further. What is the reason for exhaust levels in the kitchen? As previously mentioned, the answer is simply to remove the heat and cooking effluent generated during the cooking process. With this in mind, what is the most accurate method of determining the exhaust quantity required in the kitchen? It should begin with the heat load generated by the cooking process. Any other method of determination (such as cfm/foot, cfm /ft^2, etc.) will not provide an accurate result. Only by basing HVAC operation on the total loads (conduction, convection and radiation loads) present in the space can an accurate determination be made. And only by an accurate determination can a good operating system be designed.

Many manufacturers of commercial kitchen ventilation equipment offer design methods for determination of exhaust based on cooking appliances. Any method used is better than no quantification at all.

The method of determining exhaust levels based on the heat generated by the cooking process is referred to as heat load based design and is the premise for this manual. It is the foundation of accurate and correct design fundamentals in a commercial kitchen environment.

1.2 Initial Design Considerations

Kitchens operate year round and when outside air temperatures are above 48˚F cooling is almost always required. This is due to the heat loads generated in a commercial kitchen from the cooking processes.

The modes of heat gain to a space may include (1) solar radiation through transparent surfaces, (2) heat conduction through exterior wall and roofs, (3) heat conduction through interior partitions, ceilings, and floors, (4) heat generated within the space by occupants, lights, and appliances, (5) energy transfer as a result of ventilation and infiltration of outdoor air, and (6) miscellaneous heat gains (see Ref 1). However, in commercial kitchens, cooking processes contribute the majority of heat gains to the space.

Sensible heat (or dry heat) is directly added to the conditioned space by conduction, convection and radiation. Latent heat gain occurs when moisture is added to the space (e.g., from vapor emitted by cooking process, equipment and occupants). Space heat gain by radiation is not immediate. Radiant energy must first be absorbed by the surfaces enclosing the space (walls, floor, and ceiling) and by the objects in the space (furniture, people, etc.). As soon as these surfaces and objects become warmer than the space air, some of the heat is transferred to the air in the space by convection (see ref. 1).

To calculate a space cooling load, detailed building design information and weather data at selected design conditions are required. Generally, the following information is required:

- building characteristics
- configuration (e.g, building location)
- outdoor design conditions
- indoor design conditions
- operating schedules
- date and time of day

1.3 Heat Gain and Emissions Inside The Kitchen

Cooking can be described as a process that adds heat to raw or precooked food. As heat is applied to the food, effluent is released into the surrounding environment. This effluent release includes water vapor, organic material released from the food itself, and heat that was not absorbed by the food being cooked. Some forms of reheating, such as rethermalization limit the effluent released to the space but still emit water vapor to the surrounding space.

The hot cooking surface (or fluid, such as oil) and product create thermal air currents (typically called a thermal plume) that are received or captured by the hood and then exhausted. If this thermal plume is not captured and contained by the hood, they become a heat load to the space. The velocity of these thermal plumes depends largely on the surface temperature of the cooking equipment, and varies from 25 feet per minute over some steam equipment, to 200 feet per minute over some char-broilers. Because of this variation, cooking equip ment is typically classified in four categories: light duty (such as ovens, steamers, and small kettles up to 400˚F), medium duty (such as large kettles, ranges, griddles, and fryers up to 400˚F), heavy duty (such as broilers, char-broilers, and woks up to 600˚F) and extra heavy duty (such as solid-fuel-burning equipment up to 700˚F). By far, in a commercial kitchen, cooking and refrigeration equipment contribute to a majority of the heat loads in the space.

However there are numerous secondary sources of heat in the kitchen (such as lighting, people, and hot meals) that contribute to the cooling load as presented in Table 1.

Table 1. Cooling load from various sources

Load	BTU/H	W
Lighting	6-16/ft^2	2-5/ft^2
People	450/person	130/person
Hot meal	50/meal	15/meal
Cooking eq.	varies	varies
Refrigeration	varies	varies

1.4 Ventilation Rate

The airflows and air distribution methods used in the kitchen should provide adequate ventilation in the occupied zone, without disturbing the thermal plume as it rises into the hood system. ASHRAE Standard 62-1999 (See Ref 2) states that the estimated maximum occupancy for the kitchen is 20 persons per every 1000 ft^2. The minimum outdoor air requirement is 15 cfm/person. The sum of the outdoor air and transfer air of acceptable quality from adjacent spaces should be sufficient to compensate for exhaust airflow rate of not less than 1.5 cfm/ft^2.

The location of supply and exhaust units are also important for providing permissible ventilation. Ventilating systems should be designed and installed so that the ventilation air is supplied equally throughout the occupied zone. Some common faults are to locate the supply and exhaust units too close to each other, causing 'short-circuiting' of the air directly from the supply opening to the exhaust openings. Also, placing the high velocity supply diffusers too close to the hood system reduces the ability of the hood system to provide sufficient capture and containment (C&C) of the thermal plume. Recent studies show that the type of air distribution system utilized affects the amount of exhaust needed to capture and contain the effluent generated in the cooking process.

1.5 Ventilation Effectiveness and Air Distribution Systems

Ventilation effectiveness can be described as the ability of ventilation system to provide design conditions in the space (air temperature, humidity, concentration of impurities and air velocity) at minimum energy consumption. In commercial kitchen environment the airflow rate required to compensate for hoods exhaust and ventilate the space is the primary factor contributing to the system energy consumption. In this chapter we will review different air distribution systems and their affect on kitchen ventilation effectiveness.

There have traditionally been advocates choosing either high velocity mixing or low velocity mixing systems. Now there is a third alternative that clearly demonstrates improved thermal comfort over the other systems.

Refer to section 3.3 for the detailed comparison between mixing and displacement systems in a typical kitchen environment.

1.5.1 Mixing Ventilation

Mixed air supply registers supply high velocity air at the ceiling level. This incoming air is "mixed" with room air to satisfy the room temperature set point. Theoretically there should be a uniform temperature from floor to ceiling. However, since commercial kitchens have a high concentration of heat, stratification naturally occurs. Consequently, the conditioned air does lose some of its cooling effectiveness, gaining in temperature as it mixes with the warmer air at the ceiling.

Research has shown that if mixing diffusers are located close to the hood, the high velocity air interrupts the cooking plume, drawing some of it out of the hood (in effect causing the hood to 'spill') and further increasing the heat load to the space.

1.5.2 Displacement Ventilation

Thermal displacement ventilation is based on the natural convection of air, namely, as air warms, it will rise. This has exciting implications for delivering fresh, clean, conditioned air to occupants in

Specially designed displacement diffusers, made for the commercial kitchen, allow low velocity air to be introduced directly to the occupied zone, where it can do the most good.
Instead of working against the natural stratification in a kitchen, displacement ventilation first conditions the occupied zone and, as it gains heat, continues to rise toward the upper unoccupied zone where it can be exhausted.
According to VDI (Ref. 5) application of a Displacement Ventilation system allows for a reduction in hood exhaust airflow by 15% compared to a conventional mixing system.
An additional benefit of displacement systems is that since it can cool the space using higher supply temperatures (up to 65 °F), the use of an economizer becomes a more feasible energy-savings approach.

1.5.3 Integrated Approach

Even though large energy savings can be realized from individual application of various exhaust hoods and air distribution methods, the biggest energy savings potential arises when the kitchen is analyzed as an integrated system. The nature of the system directs supply air into the occupied zone and allows it to stratify. The combination of high-efficiency hoods (such as Capture-Jet hoods) with displacement ventilation can reduce the required cooling capacity, while maintaining space temperatures.
The natural buoyancy of the displacement air assists in the C&C of the convective plume by 'lifting' it into the hood.

Third-party research had demonstrated that this integrated approach for the kitchen has the potential to provide the most efficient and lowest energy consumption of any kitchen system available today.

1.6 Thermal Comfort and Productivity

Labor shortages are the top challenge that commercial restaurants face today. The average age of a restaurant worker is between 16 and 24 years. In a recent survey conducted by the National Restaurant Association (Ref 8), over 52% of respondents said that finding qualified motivated labor was their main concern.
This labor situation is not going to ease anytime soon. As seen in Table 2, the percentage of Americans younger than 20 years old is expected to drop from 29% in 2000 to 27% in 2010, and the percentage of 20-39 years old is expected to drop from 28% to 26%.

Table 2 Percent of American population by Age

Percent of Population	1990	2000	2010
Younger than 20	29%	29%	27%
20-39	33	28	26
40-59	21	26	28
60 and Older	17	17	19

One reason for the low popularity of kitchen work is the unsatisfactory thermal conditions. Thermal comfort is a state where a person is satisfied with the thermal conditions.
"If you can't stand the heat, stay out of the kitchen." This saying has been so ingrained in the American psyche that people naturally think that a commercial kitchen should be a hot and nasty environment. This does not have to be so.
There are four factors affecting thermal comfort: air temperature, radiation, air movement and humidity. Even in a laboratory controlled environment, people respond differently to the same thermal conditions. So, 100% satisfaction cannot be guaranteed. The basic aim is to specify conditions that are thermally acceptable to 80% or more of the occupants (see Ref 4).
The percentage of dissatisfied people remains under 10% in neutral conditions if the vertical temperature difference between the head and feet is less than 5-7°F and there are no other non-symmetrical temperature factors in the space. A temperature difference of 11-14°F increases the dissatisfied percentage to 40-70%.
There are also important personal parameters influencing the thermal comfort (typical values in kitchen environment in parenthesis):

- Clothing (0.5 - 0.8 clo)
- Activity (1.6 - 2.0 met)

Clo expresses the unit of the thermal insulation of clothing (1 clo = 0.88 ft^2·hr·°F/Btu) (see Ref 10). Met is a unit used to express the metabolic rate per unit Dubois area, defined as the metabolic rate of a sedentary person, 1 met = 18.43 Btu/(hr·ft^2)(see Ref 1).
Room air temperature also affects a person's capacity to work. Comfortable thermal conditions decrease the number of accidents occurring

in the work place. When the indoor temperature is too high (over 82 °F in commercial kitchens) the productivity and general comfort diminish rapidly (Figure 1).

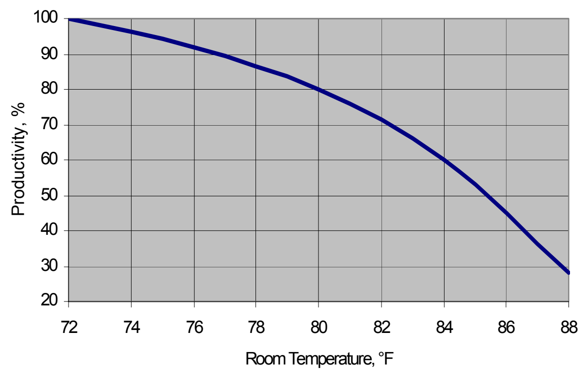


Figure 1 Productivity vs. Room Air Temperature.

The Average restaurant spends about $2,000 yearly on salaries, wages and benefits per seat. If the air temperature in the restaurant is maintained at 80°F in the kitchen the productivity of the restaurant employees is reduced to 80 % (see Figure 1). That translates to losses of about $40,000 yearly on salaries and wages for an owner of a 100-seat restaurant.

2 Kitchen Hoods

As mentioned before, the purpose of kitchen hoods is to remove the heat, smoke, effluent, and other contaminants. The thermal plume from hot appliances takes up the contaminants that are released during the cooking process. Room air replaces the void created by the plume. If convective heat is not removed directly above the cooking equipment, impurities will spread throughout the kitchen, leaving discolored ceiling tiles and greasy countertops and floors. Therefore, contaminants from stationary local sources within the space should be controlled by collection and removal as close to the source as is practical (see Ref 11).

As previously mentioned, appliances contribute most of the heat in commercial kitchens (see Ref 12). When appliances are installed under an effective hood, only the radiant heat contributes to the HVAC load in the space. Conversely, if the hood is not providing sufficient C&C, convective and latent heat are 'spilling' into the kitchen thereby increasing both humidify and temperature.

Capture efficiency is the ability of the kitchen hood to provide sufficient C&C at minimum exhaust flow rate. The remainder of this chapter discusses the evolution and development of kitchen ventilation testing and their impact on system design.

2.1 Evolution of Kitchen Ventilation Testing

In order to understand the current state of kitchen ventilation design it is important to look back at its origins. The National Fire Protection Agency took up the issues relating to commercial cooking as far back as 1946 as part of standard on blower and exhaust systems. It wasn't until 1961 that it was adopted as a separate standard that we know today as NFPA 96 (see Ref 7). This standard is primarily concerned with fire safety issues such as hood construction, clearance to combustibles, duct configuration etc. The only reference to air movement is related to duct velocity minimum (Section 5-2.2)

and make up air pressure differential (Section 5-3). Exhaust air amounts are not quantified except to state "exhaust air volumes for hoods shall be of sufficient level to provide capture and removal of grease laden vapors" (Section 5-2.2)

Model building codes such as BOCA (Building Officials Code Approval) and UMC (Uniform Mechanical Code) adapted many of the fire safety aspects of NFPA 96 in addition to quantifying air volume requirements. These air flow requirements, 100 cfm per square foot of hood area for wall canopies and 150 cfm per square foot island canopies became the norm. (Section M-504.5.1)

Numerous strategies were employed to circumvent the exhaust airflow requirement, such as short cycling the air within the hood cavity. As we will see later, this design concept is fundamentally flawed.

The advent of independent testing (such as the Underwriters Laboratories Standard 710) allowed for airflows lower than those stated in the model codes by establishing minimum airflows for a variety of appliance surface temperatures.

The further refinement of test methods (such as ASTM F1704) allowed independent testing of required exhaust flow rates under a variety of conditions, ultimately leading to a reduction in those air flows required by the 2000 International Mechanical Code for non-listed hoods.

2.1.1 Standard UL 710

The primary emphasis of the UL 710 test protocol (See ref. 13) is the establishment of a uniform standard of test for commercial ventilation systems. This test encompasses airflow testing and verification of compliance to NFPA96 construction standards. In addition, it quantifies clearances and overhang requirements of tested hood systems based on results.

The establishment of exhaust and/or supply rates for a particular hood requires placing a commercial cooking appliance (having a surface area of at least 540 in^2) underneath the test hood. The front and side overhang shall be set to the minimum required by the hood. These dimensions become part of the listing of the tested hood and must be adhered to on design and installation in order to be compliant with the model codes.

The appliance surface temperature is set to either 400 °F, 600 °F, or 700 °F (solid fuel). A griddle is used for the 400 °F testing, an underfired broiler for the 600 °F testing and a solid fuel appliance or gas conveyor-type broiler are used for the 700 °F test. The UL inspector verifies the removal of cooking vapor at the tested airflow. If, in the inspectors judgment, the hood has captured the visible cooking vapors, the hood passes at the tested exhaust rate, extrapolated to a minimum value per linear foot of hood length for the cooking duty tested.

In addition to establishing minimum air flows based on surface temperature, the Standard UL 710 verifies that hood construction is in compliance with NFPA-96. Other issues relating to the physical installation of the hood such as ductwork, fans and clearances to combustibles etc are detailed in this guideline.

The intention of the UL airflow testing was not to establish design exhaust rates, rather to establish minimum exhaust rates for purposes of fire safety and ventilation. Since the testing is based on the removal of visible cooking vapors, it falls well short of quantifying the efficiency or ability of a hood system to remove the convective heat from a given group of appliances. This leads to the use of a variety of test methods to verify system performance. They are reviewed as follows:

2.1.2 Tracer Gas Studies

Halton pioneered the research on the kitchen exhaust system efficiency in the late 1980's, commissioning a study by the University of Helsinki. At the time there were no efficiency test standards in place. The goal was to establish a test protocol that was repeatable and usable over a wide range of airflows and hood designs. Nitrous Oxide (tracer gas), a neutrally buoyant gas was used. A known quantity of gas was released from the heated cooking surface and compared to concentration measured in the exhaust duct. The difference in concentration was the efficiency at a given air flow. This provided valuable information about the potential for a variety of C&C strategies. The Capture-Jet™ system was tested using Tracer Gas technique and the results showed a significant improvement in C&C of the convective plume at lower exhaust airflows compared to conventional exhaust only hoods.

2.1.3 ASTM F1704

In 1990, AGA Laboratories was funded by the Gas Research Institute to construct a state-of-the-art kitchen ventilation laboratory and research the interaction between cooking appliances, kitchen ventilation hoods, and the kitchen environment. In early 1993, the original Energy Balance Protocol was developed to explain the interaction between the heat loads in the kitchen. Mathematically, the energy consumed by the cooking appliance can only go three places:

- To the food being cooked
- Out the exhaust duct
- Into the kitchen as heat load

In late 1993, this was introduced as a draft standard to be adopted by ASTM and was called the Energy Balance Protocol. The original protocol was developed to only examine the energy interactions in the kitchen with the goal of determining how much heat was released into the kitchen from cooking under a variety of conditions. This standard was adopted by ASTM as F1704.

Around 1995, the standard adopted new methods of determining the C&C using a variety of visualization techniques including visual observation, neutrally buoyant bubbles, smoke, lasers, and Schlieren thermal imaging (discussed in more detail later in this section).

The test set up includes a hood system operating over a given appliance. Several thermocouple trees are placed from 6 to 8 ft. in the front of the hood system and are used to measure the heat gain to the kitchen space. This enables researchers to determine the temperature of

room air being entrained into the hood.
In theory, when the hood is providing sufficient C&C, all of the convective plume from the appliance is exhausted by the hood while the remaining radiant load from the appliance is heating up the hood, kitchen walls, floors, ceiling, etc. that are eventually seen as heat in the kitchen.

2.1.4 Schlieren Thermal Imaging

Schlieren thermal imaging has been around since the mid 1800's but was really used as a scientific tool starting in the late 20th century. During the 1950's Schlieren thermal imaging was used by AGA Laboratories to evaluate gas combustion with several different burner technologies. NASA has also made significant use of Schlieren thermal imaging as a means of evaluating shockwaves for aircraft, the space shuttle, and jet flows. In the 1990's Penn State University began using Schlieren visualization techniques to evaluate heat flow from computers, lights, and people in typical home or office environments. In 1998 the kitchen ventilation lab in Chicago purchased the first Schlieren system to be used in the kitchen ventilation industry. In 1999, Halton Company became the first ventilation manufacturer globally to purchase a Schlieren thermal Imaging system for use in their research and development efforts.
By using the thermal imaging system we can visualize all the convective heat coming off an appliance (not just what is visible as is the case with the U.L. 710 test) and determine whether the hood system has sufficient C&C. In addition to verifying C&C levels, the impact of various supply air and air distribution measures can be incorporated to determine the effectiveness of each. By using this technology a more complete understanding of the interaction between different components in the kitchen (e.g., appliances, hoods, make-up air, supply diffusers, etc.) is being gained.

2.1.5 Computer Modeling

Computational Fluid Dynamics (CFD) has been used in the aerospace and automobile industries for a number of years. Until recently, it was extremely expensive for wide spread use. The cost of the hardware alone made it prohibitive for all but a few large companies. With improvement in processing speed and reduction in costs of some very powerful machines, CFD use has become more widespread, specifically in the HVAC industry.
CFD works by creating a three-dimensional computer model of a space. Boundary conditions, in the case of kitchen ventilation modeling, may include; hood exhaust rates, input energy of the appliance, supply air type and volume and temperature of supply air. Complex formulas are solved to produce the final results. After the solutions converge, variables such as temperature, velocity, and flow directions can be visualized. CFD has become an invaluable tool to the researcher by providing an accurate prediction of results prior to full scale mock-ups or testing for validation purposes.

2.2 Types of Hoods and Filters

Kitchen ventilation hoods are grouped into one of two categories. They are defined by their respective applications:

- **TYPE I**: Is defined for use over cooking processes that produce smoke or grease laden vapors and meets the construction requirements of NFPA-96
- **TYPE II:** Is defined for use over heat or water vapor producing cooking or dishwashing processes.

Additional information on Type I and Type II hoods can be found in Chapter 30 of the 1999 ASHRAE HVAC Applications Handbook. This section presents information on engineered, low-heat hoods, and commodity classes of hoods as well as an overview of the most common types of grease removal devices.

2.2.1 Engineered Hood Systems

This subsection presents the engineered hood products offered by Halton Company. These systems are factory built and tested in accordance with U.L. 710 and ASTM F1704 protocols and are considered high-efficiency systems. These systems have been tested using tracer gas technique, Schlieren visualization, and computer modeling to measure system efficiency. Common to these designs is the use of Capture-Jet™ technology to improve the C&C efficiency of the hood.

Capture-Jet™ Canopy Hoods

These wall style canopies incorporate the jet technology to prevent 'spillage' of grease-laden vapor out from the hood canopy at low exhaust rates. A secondary benefit coupled with the low-pressure loss, high efficiency multi cyclone grease extractor (Model KSA) is to create a push/pull effect within the capture area, directing the grease-laden vapors toward the exhaust. Performance tests indicate a greater than 30% reduction in exhaust rate over exhaust only devices.

Capture-Jet™ Back Shelf Hood

Incorporates the use of jets in a unique way. Due to the proximity to the cooking surface, the jet is used as an air curtain, extending the physical front of the hood toward the cooking surface without impeding the thermal plume. The result from independent testing shows a 27% decrease in exhaust over conventional back shelf design during full load cooking and a 51% reduction during idle cooking.

Capture-Jet™ V bank Island

For use with a single row of appliances in an island configuration. This system incorporates the use of the jets on both sides of the V bank, directing rising heat and effluent toward the extractors.

Capture-Jet™ double island canopy

For use over back-to-back appliance layout. This system incorporates two Capture-Jet™ canopies, back to back to cover the cooking line up.

2.2.2 Low Heat Applications

There are some applications where there is no grease load from the cooking process and only small amounts of heat or water vapor are being generated. Three options are presented here depending on the application.

Exhaust Only Hoods

These type systems are the most rudimentary design of the Type I hood, relying on suction pressure and interior geometry to aid in the removal of heat and effluent. Typical applications include steamers and other small equipment on the prep-line of a kitchen.

Condensate Hoods

Construction follows National Sanitation Foundation (NSF) guidelines. A subcategory of Type II hoods would include condensation removal (typically with an internal baffle to increase surface area for condensation.)

Heat Removal, Non-Grease Hoods

These Type II hoods are typically used over non-grease producing ovens. Box style is the most common. They may be equipped with lights and have an aluminum mesh filter in the exhaust collar to prevent large particles from getting into the ductwork.

2.2.3 Commodity Type Hoods

Short Cycle

These systems, no longer advocated by the industry, were developed when the exhaust rate requirements followed the model codes exclusively. With the advent of U.L. 710 testing and a more complete understanding of thermal dynamics within the kitchen, use of short cycle hoods have been in decline. The concept allowed for the introduction of large volumes of untreated make up air directly into the exhaust canopy. The ratio of make up air to exhaust air was as high as 80% and in some extreme cases, 90%. It was assumed that the balance drawn from the space (known as “net exhaust”) would be sufficient to remove the heat and effluent generated by the appliances. This was rarely the case since the design did not take into account the heat gain from the appliances. This further led to a domino effect of balancing and rebalancing of the hood that ultimately stole air-conditioned air from the dining room. In fact, testing by hood manufacturers has shown that the net-exhaust quantities must be nearly equal to the exhaust through an exhaust-only hood to achieve a similar C&C performance for short-circuit hoods.

Exhaust Only with Back Return

As the use of short cycle hoods decline, other means of introducing untempered make up air have been attempted. The most notable is the back return plenum. The idea behind the back return plenum is to introduce untempered make air into the space. The implication is that the exhaust hood would simply take this untempered air, along with the thermal plume and exhaust it, without adding any additional heat load to the kitchen space. Testing results for this type of system are presented in Section 2.3.3.

Ductless hoods

In certain applications it is cost prohibitive to run a welded exhaust duct. This is typically seen in urban high-rise applications. To address this type of application, ductless hoods have been developed. Also known as kiosk hoods, they come in two basic filter configurations. These systems can be close coupled with a specific appliance or be design for a complete cook line.
These systems may have an electrostatic precipitator (ESP) and/or a series of increasingly efficient media type filters, typically including a hospital grade HEPA. These systems also incorporate a charcoal filter to deal with odor absorption. As the filters become loaded, their effi

ciency increases. At a point where maintenance is required, a pressure indicator will alert personnel to change filters. The system cannot operate with dirty filters, alleviating a problem associated with ESP type systems.
In either type system, the heat generated by the appliances is discharged to the space and must be considered when calculating the cooling load for the space. It is usually recommended that general exhaust and supply is incorporated in the design to provide the proper air change rate for the space and prevent heat buildup.

Water Wash

Water wash systems are often thought of in terms of grease extraction efficiency. In fact this type of system has little or no impact on the grease extraction efficiency of the hood but is a device to facilitate cleaning of the filters. The basic premise of the water wash hood is the ability to “wash down” the exhaust plenum within the hood as well as the mechanical grease extraction device. A secondary benefit is said to be an aid to fire suppression. Water wash hoods come in a variety of configurations as far as hood geometry goes. These follow fairly closely the “dry” hood styles.

2.2.4 Grease Removal Devices

Another item of interest in a kitchen is the variety of grease removal devices available to the end-user. Different manufacturers offer different types of hoods with various combinations of grease removal devices.

Electrostatic Precipitators (ESP)

ESP’s work by positively or negatively charging a grease particle and then utilizing a series of oppositely charged collecting plates to attract the grease particle. These systems must be vigorously maintained to keep the grease collecting efficiency. If the cells become loaded, grease-laden vapors will continue to be emitted into the space. Typically a charcoal filter is incorporated to absorb odors from the cooking process.

Slot Filters

There is a high velocity slot where grease-laden vapors enter the exhaust plenum. Within the plenum there is an alternating staggered lip, which redirects the air, creating a wiping or centrifugal action. It is said to produce a high level of grease extraction. Recent testing by ASHRAE put these claims into question. RP-851 measured grease efficiency based on EPA Method 5 and found the slot ventilators to have effi ciency not much greater than an open duct. This type of filter is most commonly utilized in water wash ventilators.

Cartridge Filters

These extractors can be viewed in terms of a compressed baffle filter. Due to higher surface area and restricted opening, they have higher extraction efficiency than slot type ventilators. With the higher extraction method, comes a higher static pressure.

Baffle Filters

These extractors have a series of vertically aligned baffles that collect grease by directing the airflow through two 180° turns thereby causing the grease to impact the sides of the filter and stick.

Cyclonic Modular Filters

This is a non-generic Halton KSA filter that uses cyclonic effect to improve filtration efficiency compared to traditional baffle filters. For more information on this type of filters refer to section 6.3.

Continuous Mist

This added feature of some water wash ventilators sprays a continuous cold-water mist into the exhaust air stream and is claimed to congeal grease and increase the extraction rate.

Rooftop Systems

There are also several types of rooftop systems available that incorporate many of these technologies (including filter media, water mist, etc.). The major drawback of these systems is their high capital cost and continuous maintenance cost to replace the filters.

2.3 Hoods Comparison Studies

In this section a variety of techniques and research findings are presented that demonstrate the performance and value that Halton’s products offer the end-user. There is a discussion on the ineffectiveness of some hood designs offered by Halton’s competitors followed with a discussion of how capture efficiency impacts the energy use, and ***energy bills***, of the end-user.

2.3.1 KVE Case Study

Halton is using state-of-the-art techniques to validate hood performance. These include modeling of systems, using CFD, Schlieren imaging systems, and smoke visualization. All the test results presented here have been validated by third-party research.

Halton's standard canopy hood (model KVE) utilizes Capture-Jet™ technology to enhance hood performance, and consequently hood efficiency, versus the competition.

In this case study, the KVE hood has been modeled using CFD software. Two cases were modeled for this analysis: one with the jet's turned off – in effect this simulates a generic exhaust only canopy hood and a second model with the jet's turned on. As can be seen from observing Figures 2 and 3 is that, at the same exhaust flow rate, the hood is spilling when the jets are turned off and capturing when they are turned on.

The same studies were conducted in the third party laboratory, but Schlieren Thermal Imaging system was used to visualize the plume and effect of Capture Jet™. As one can see the CFD results are in good agreement with the Schlieren visualization, see Photos 1 and 2.

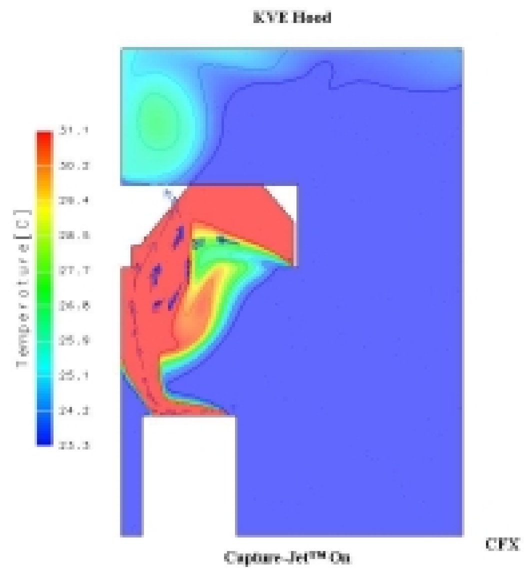


Figure 3 KVE With Jets On

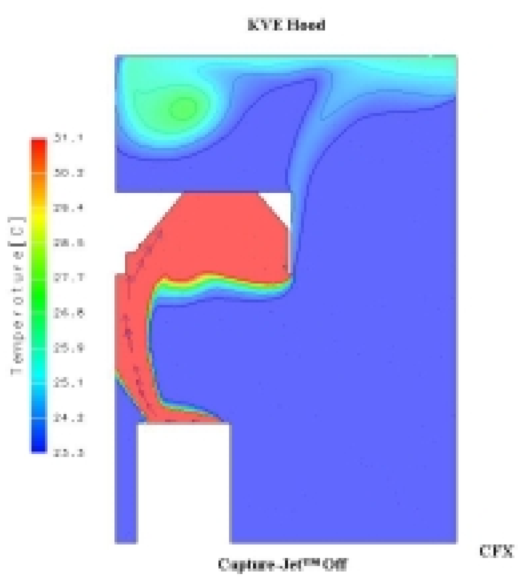


Figure 2 KVE With Jets Off

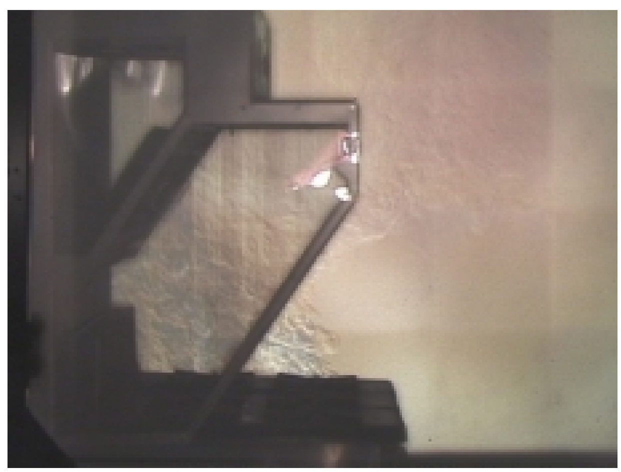


Photo 1 Schlieren Image of KVE Hood. Capture Jet™ Off

Photo 2 Schlieren Image of KVE Hood. Capture Jet™ On

2.3.2 KVL Case Study

Independent research has been performed to evaluate the capture efficiency of Halton's back shelf style (model KVL) hood.
The first set of results for the KVL hood demonstrate the capture efficiency using a Schlieren thermal imaging system. Note that the hood has been manufactured with Plexiglas sides to allow the heat inside the hood to be viewed. Photos 3 and 4 show the results of the KVL hood with the jets turned off and on at the same exhaust air flow, respectively. Once again, it becomes readily apparent that the Capture-Jet™ technology significantly improves capture efficiency. The KVL hood is spilling with the jets turned off and capturing when the jets are turned on.

Photo 3 Schlieren Image of KVL hood. Capture Jet™ Off

Another study conducted in-house was to model these two cases using CFD in order to see if the CFD models could predict what was observed in a real world test. Figures 4 and 5 present the results of the CFD models for jets off and jets on, respectively. Note that the jets in the KVL hood are directed downward, where they were directed inward on the KVE hood discussed earlier. If you were to place downward directed jets on the KVE hood, it would actually cause the hood to spill instead of capture. This is testimony to the importance of performing in-house research and is just one value added service provided by Halton Company.

Photo 4 Schlieren Image of KVL Hood. Capture Jet™ On

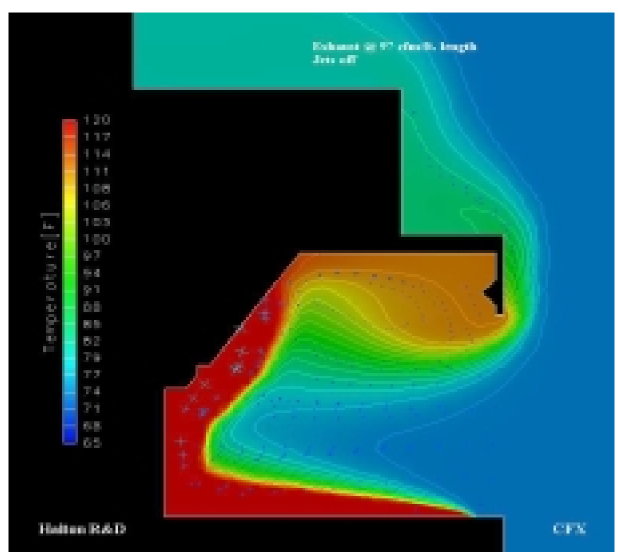


Figure 4 CFD Results of KVL Hood With Jets Off

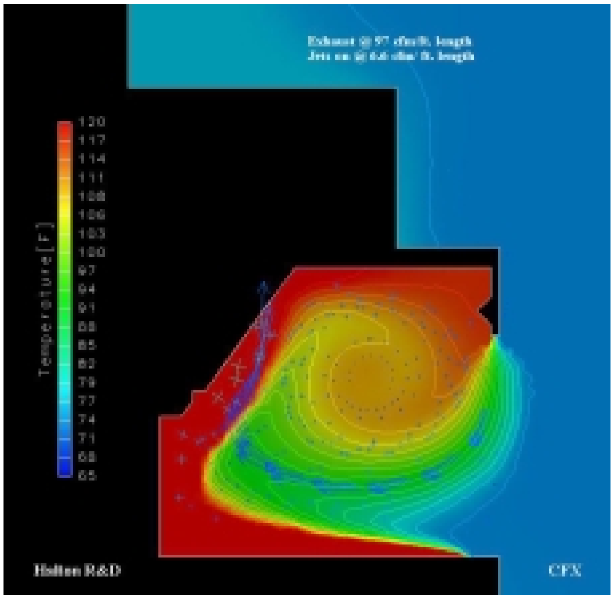


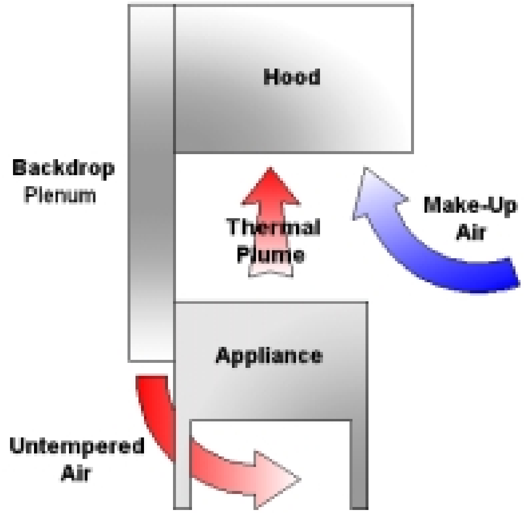
Figure 5 CFD Results of KVL Hood With Jets On

When you compare the CFD results to those taken with the Schlieren system for the KVL hood, you'll note that they produce markedly similar results. This demonstrates that not only can CFD models be used to model kitchen hoods but they can also augment laboratory testing efforts.

2.3.3 Backdrop Plenum Case Study

The backdrop plenum hood is a relatively new style of hood on the market, replacing the older short-circuit (also called integral makeup) style of hood. Years of experience have proven that short-circuit hoods are not very effective and are troublesome to get to operate correctly with large amounts of untempered air.

The backdrop plenum differs from the short-circuit hood in terms of where the untempered air is brought into the hood. In a short-circuit hood untempered air is introduced directly into the hood cavity while with a backdrop plenum hood, untempered air is brought in behind the appliance as shown in Figure 6. The purpose of this case study was to compare the backdrop plenum hood to an exhaust-only hood with respect to performance and comfort in the kitchen. The tools used in this study include CFD models, visualization with smoke, and a thermal mannequin to measure kitchen comfort.



CFD Analysis

The first comparison for this study was a CFD model comparing the exhaust-only hood against the backdrop plenum hood. For the exhaust-only model, 100% of the makeup air was supplied from mixing diffusers in the kitchen at a temperature of 57 °F. The backdrop plenum hood was modeled using 20% makeup air at 57 F in the kitchen with 80% of the makeup air from the backdrop plenum at a temperature of 95 °F (simulating summer conditions). The exhaust flow rate out of the hood in both cases was 750 cfm. A gas under-fired broiler was placed under the hood operating at 100,000 Btu/hr. Figures 7 and 8 show the difference in kitchen temperature between these two cases.

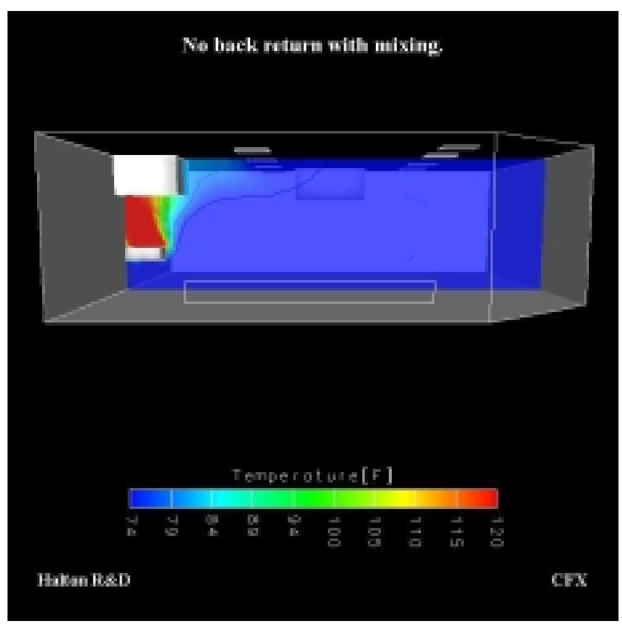


Figure 7 CFD Results of Kitchen Temperature With An Exhaust-Only Hood

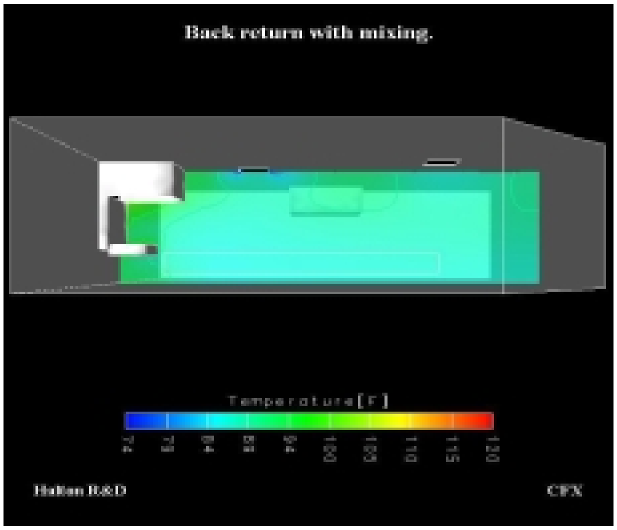


Figure 8 CFD Results of Kitchen Temperature With A Backdrop Plenum Hood

Upon examination of Figures 7 and 8, it becomes apparent that the average kitchen temperature is significantly cooler (79 vs. 89 °F) with the exhaust-only hood. One explanation for the difference becomes apparent when we observe the CFD model of the airflow out of the backdrop plenum hood as shown in Figure 9. It can be observed that a majority of the makeup air from the backdrop plenum hood actually enters the kitchen space and causes an increase in space temperature.

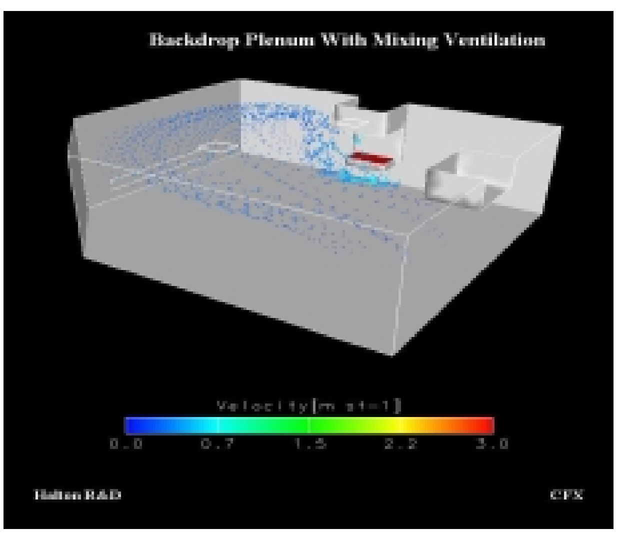


Figure 9 Airflow from Backdrop Plenum Hood

What will happen in the kitchen if the backdrop plenum hood actually does capture the air coming in from the backdrop plenum? Let's refer to the heat gain from appliances as shown in Figure 10. If we assume that all of the convective load from the appliance is captured by the hood, there is still a significant radiation load that reaches the kitchen. Remember that ***NO*** hood system can eliminate the radiation load from the appliances, it must be accounted for in the kitchen HVAC design.

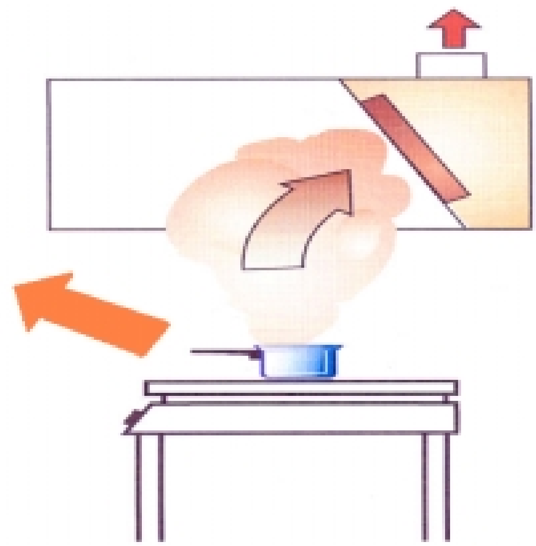


Figure 10 Appliance Heat Gain to Space

Untempered air, introduced through the backdrop plenum reduces the amount of air-conditioned make-up air required to ventilate the kitchen space – that is the only reason why backdrop plenum hoods are being utilized. However, when kitchen makeup air (dedicated or transfer air from the dining space) is reduced from 100% to 20% (hood with 80% airflow supplied through the backdrop plenum) there won't be adequate cooling in the kitchen as will be demonstrated later in this section. It is conventional thinking that the makeup air, that is used to replace air exhausted by the kitchen hood, is wasted air. In fact, it serves a useful function in the kitchen, by maintaining design room air temperature, sweeping heat and contaminants from the kitchen before it exits through the hood.

Smoke Video

One of the other tests to validate the CFD results was to introduce smoke into the backdrop plenum in order to visualize what happens to the makeup air as presented in Photo 5. It is evident that, once again, the makeup air from the backdrop plenum is spilling into the kitchen and not being captured by the hood. This verifies that the CFD model accurately predicted what would happen to the air from the backdrop plenum.

Photo 5 Smoke From Backdrop Plenum

Thermal Comfort Analysis

The final test conducted was to compare the comfort of a chef standing in front of an underfired broiler with an exhaust-only hood versus a backdrop plenum hood. Data for these tests were collected using a breathing thermal mannequin shown in Photo 6.

Photo 6 Breathing Thermal Mannequin

A comparison of kitchen comfort results for the exhaust-only and backdrop plenum hoods, using mean thermal vote (MTV) is presented in Table 3. As can be seen from the data, red indicates that a portion of the body is uncomfortably warm. In the case of the backdrop plenum hood virtually the entire body is uncomfortable versus the exhaust-only hood that only has some portions of the body uncomfortable.

Body Section	Exhaust-Only Mixing	Backdrop Plenum Mixing
hair	3.60	4.17
face	8.25	7.85
neck	3.22	3.48
right upper back	0.67	3.32
left upper back	0.53	1.87
right chest	6.81	5.90
left chest	5.75	5.34
left lower back	2.05	3.37
right upper arm	3.81	4.14
right lower back	1.01	3.28
left upper arm	3.75	3.95
right lower arm	4.74	3.97
left lower arm	2.95	3.65
right hand	5.01	4.37
left hand	3.14	4.31
hips	2.82	3.58
right thigh	2.06	3.49
left thigh	2.40	3.63
right lower leg	1.24	2.88
left lower leg	1.38	2.74
right ankle	1.30	2.82
left ankle	1.63	2.56
right foot	-0.42	2.91
left foot	-1.18	2.34

Color Key:
- Satisfied
- Cold
- Hot
- Warm

Table 3 MTV Results After 20 Minutes in Front of Under-Fired Broiler

Keeping in mind that these test were conducted with hot and humid (95 °F) untempered air, what can we hypothesize about the effect of the backdrop plenum hood in the winter. If we assume that the air will be heated to 40 °F, the chef will have 40 °F air at his feet and 80 to 90 °F air at his/her head resulting in a temperature difference over the body of 40 to 50 °F. Contrast this with the exhaust only case where a temperature difference of around 15 °F can be observed. The backdrop plenum hood may cause a decrease in both the comfort and general health of kitchen staff during the winter months.

2.3.4 Energy and Cost Comparison Using the HEAT™ Software

This section will show the energy and cost benefits for the end-user of utilizing Halton's Capture Jet™ hood system versus the competitions exhaust-only and short-circuit hoods. The data entry screen for the HEAT™ software is shown in Figure 11.

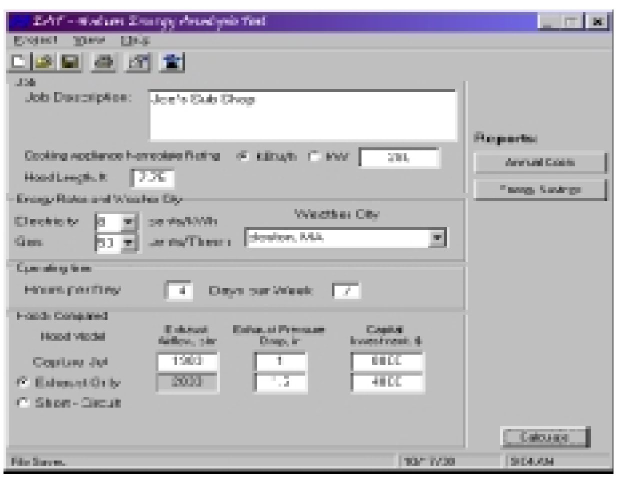


Figure 11 Main HEAT™ Screen

As shown in Figure 11, we are comparing two systems: a Halton model KVE hood with Capture-Jet™ technology versus a competitor's exhaust-only hood. The store being modeled is a sandwich shop that has two deep-fat fryers and a griddle underneath the hood. The store also has an oven/proofer that is not placed under a hood. The total nameplate rating of the appliances is 180,000 Btu/hr of natural gas and the hood length is 93 inches (entered as 7.75 ft.). The store is located in Boston, Massachusetts and has an energy rate of 8 ¢/kWh for electricity and 50 ¢/Therm for natural gas. Using Halton's HELP software it has been determined that the exhaust flow for the Capture-Jet™ hood is 1,983 cfm.

The remaining inputs on the screen are the total fan pressure drop for each of the systems along with the total installed cost for the end-user, which includes the hoods, fans, labor, etc. The final step on the main form is to press the Calculate button. Pressing the Annual Costs button will bring up the screen shown in Figure 12.

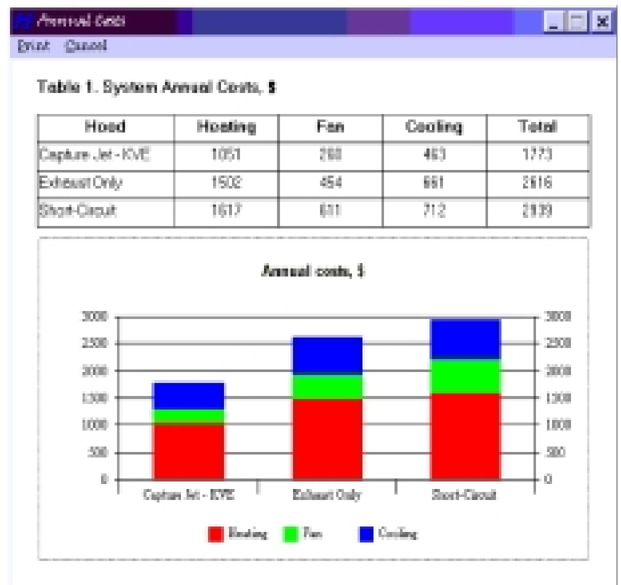


Figure 12 HEAT™ Annual Cost Screen

This screen presents the annual heating, cooling and air-conditioning operating costs for the three different hood types. However, in this case we have only specified inputs for the Capture Jet™ and exhaust-only hoods.

Pressing the Energy Savings button on the main screen brings up the report seen in Figures 13 and 14.

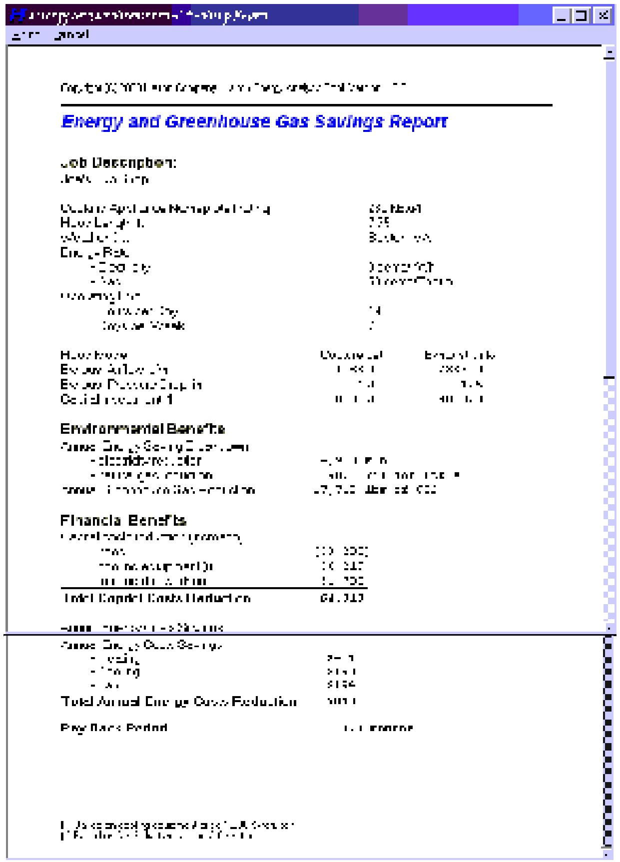


Figure 13 HEAT™ Savings Report Screen

The energy savings report presents the financial and environmental benefits of investing in a Halton system. In this case, the savings in air-conditioning were less than the added cost of the Halton hood providing an immediate payback to the end-user. Since the Capture Jet™ hood requires lower exhaust flow than a competitors hood, less make-up air is required resulting in lower air-conditioning costs.

3 Design Guidelines

This chapter presents design guidelines for sizing the exhaust hoods using heat load based design and designing displacement ventilation systems.

3.1 Design Principles

The lower the exhaust air flow, and the higher the exhaust duct temperature, at full C&C the more efficient the hood systems is. Many designers do not consider hood efficiency. The "box is a box" syndrome is prevalent with many people. However, each and every hood system, due to internal construction and added performance variables, offers a differing efficiency when related to exhaust flows required to obtain C&C. This section discusses the dimensioning of hoods and an in-depth look at heat load based hood design.

3.1.1 Hood Dimensioning

The size of the exhaust hood in relation to the cooking equipment is an important design consideration. Typically, the hood must extend beyond the cooking equipment: on all open sides for a canopy style hood and on the ends for a back shelf style system. For UL Listed hoods, the systems must overhang the cooking equipment minimally in accordance with the manufacturer's listing.

The movement of people and opening of windows and doors in the kitchen create drafts and also affect the ideal shape of the thermal plume. In a typical situation, if a hood system is not capturing and containing the effluent from the cooking process, it will spill in the front corners of the hood. In most instances, extending the overhang of a hood system from the typical six inches to twelve inches will help insure C&C in most kitchen settings

3.1.2 Heat Load Based Design

It is still a common practice to estimate exhaust air flows of hoods based on very rough "rules-of-thumb." One of these rules for wall-mounted canopy hoods is to exhaust 100 cfm per square foot of hood face area (national code requirement). If all four sides of the hood are open (island hood), the rule has been to use 150 cfm/ft^2 of hood face area. Neither of these rules takes into account the type of cooking equipment under the hood and typically results in excessive exhaust airflow and hence oversized air handling units coupled with high energy consumption rates.

The most accurate method to calculate the hood exhaust airflow is a heat load based design. This method is based on detailed information of the cooking appliances installed under the hood including type of appliance, its dimensions, height of the cooking surface, source of energy and nameplate input power. All this data allows calculating how the particular appliance emits energy into the kitchen. Part of this energy is emitted to the space in the form of the convective plume - hot air rising from the cooking surface. The other part is rejected into the space by radiation warming up the kitchen surfaces and eventually the air in the kitchen.

The Amount of air carried in a convective plume over a cooking appliance at a certain height can be calculated using Equation 1 (See Ref 5).

$$q_p = k \cdot (z+1.7D)^{5/3} . Q_{conv}^{1/3} . K_r \quad (1)$$

Where

q_p - *airflow in convective plume, cfm*
z - *height above cooking surface, in*
Q_{conv} - *cooking appliance convective heat output, Btu/h*
k - *empirical coefficient,* k = *61 for a generic hood*
Kr - *reduction factor, taking into account installation of cooking appliance (free, near wall or in the corner)*
D_h - *hydraulic diameter, in*

$$D_h = \frac{2L \cdot W}{L+W}$$

L,W - *length and width of cooking surface accordingly, in*

Kitchen hoods are designed to capture the convective portion of heat emitted by cooking appliances, thus the hood exhaust airflow should be equal or higher than the airflow in the convective plume generated by the appliance. The total of this exhaust depends on the hood efficiency.

$$q_{ex} = q_p . K_{hoodeff} . K_{ads} \quad (2)$$

Where

$K_{hoodeff}$ - *kitchen hood efficiency.*
K_{ads} - *spillage coefficient taking into account the effect of the air distribution system on convective plume spillage from under the hood. The recommended values for* K_{ads} *are listed in the table below.*

The kitchen hood efficiency shown in equation 2 can be determined by comparing the minimum required C&C flow rates for two hoods that have been tested using the same cooking process. Table 4 presents recommended values for spillage coefficient as function of air distribution system

Type of air distribution system	K_{ads}
Mixing ventilation	
Supply from wall mounted grills	1.25
Supply from the ceiling multicone diffusers	1.2
Displacement ventilation	
Supply from ceiling low velocity diffusers	1.1
Supply from low velocity diffusers located in the work area	1.05

Table 4 Spillage Coefficients As A Function of the Air Distribution System) Ref 5)

For the short-cycle hoods equation 2 will change into (see Ref 5)

$$q_{ex} = q_p . K_{hoodeff} . K_{ads} + q_{int} \quad (2.1)$$

Where

q_{int} - *internal discharge airflow, cfm*

The Heat Load based design gives an accurate method of calculating hood exhaust airflow as a function of cooking appliance shape, installation and input power, and it also takes into account the hood efficiency. The only disadvantage of this method is that it is cumbersome and time-consuming if manual calculations are used. Halton Engineering Layout Program (H.E.L.P.™) is specially designed for commercial kitchen ventilation and turns the cumbersome calculation of the heat load based design into a quick and easy process. It contains the upgradeable database of cooking appliances as well as Halton Capture-Jet™ hoods with the information sufficient to use Equations 1 and 2 to accurately calculate hood exhaust airflow.

3.2 Total Kitchen Ventilation System Design

A properly designed and sized kitchen hood will insure that effluents and convective heat (warm air) from cooking process are captured, however, it is not enough to guarantee the kitchen space temperature is comfortable. The radiation load from appliances underneath the hood, heat from appliances not under the hood, people, lights, kitchen shell (heat transfer through walls and ceiling), solar load, and potential heat and moisture from untreated makeup air are to be handled by the kitchen air conditioning system. It is recommended that a negative air balance be maintained in the kitchen. A simple rule of thumb is that the amount of air exhausted from the kitchen should be at least 10% higher than supply airflow into the kitchen. This will guarantee that the odors from kitchen do not spread to the adjacent spaces. Equation 3 describes the airflow balance in a kitchen

$$M_s + M_{tr} = M_{hood} \quad (3)$$

Where

M_s - *mass flow rate of air supplied in the kitchen (outside supply air delivered through the air handling unit and makeup* air), lb/h

$M_s = M_{osa} + M_{mu}$

M_{tr} - mass flow rate of transfer air entering the kitchen from the adjacent spaces, lb/h

M_{hood} - mass flow rate of exhaust air through the hoods, lb/h

The supply air temperature *ts* to maintain design air temperature in the kitchen is estimated from the energy balance equation shown below:

$$M_s \cdot c_p \cdot p_s (t_r - t_s) + M_{tr} \cdot c_p \cdot p_{tr} (t_r - t_r) + Q_{sens} = 0 \quad (4)$$

Where

c_p - specific heat of air = 0.24 Btu/(lb·°F)

ρ_s, ρ_{tr} - air density of supply and transfer air accordingly, lb/ft³

t_r - kitchen design air temperature, °F

t_s - supply air temperature, °F

t_{tr} - transfer air temperature, °F

Q_{sens} - total cooling load in the kitchen, Btu/h from appliance radiation, unhooded appliances, people, lights, solar load, etc.

In case the supply air temperature t_s calculated from equation 4 is below 57°F (55°F off-coil temperature with 2°F duct heat gain), the supply airflow rate M_s must be increased. The new value for M_s is calculated from the same equation 4 by setting t_s= 57°F. In this case, we recommend incorporating a return air duct to increase supply airflow.

Since it is rare that all the equipment is simultaneously operating in the kitchen, the heat gain from cooking appliances is multiplied by the reduction factor called the simultaneous coefficient, defined in Equation 5. Recommended values are presented in Table 5

$$K_{sim} = \frac{Number\ of\ appliances\ in\ use}{Total\ number\ of\ appliances\ in\ kitchen} \quad (5)$$

Table 5 Recommended values for simultaneous coefficient

Kitchen Type	Simultaneous coefficient K_{sim}
Hotel	0.8 - 0.6
Hosptial	0.7 - 0.5
Cafeteria	0.7 - 0.5
School	0.8 - 0.6
Restaurant	0.8 - 0.6
Industrial	0.8 - 0.6

3.3 Effect of Air Distribution System

Equation 4 assumes that a mixing air distribution system is being utilized and that the exhaust/return air temperature is equal to the kitchen air temperature (assuming fully mixed conditions). Conversely, a displacement ventilation system can supply low velocity air directly into the lower part of the kitchen and allow the air to naturally stratify. This will result in a higher temperature in the upper part of the kitchen while maintaining a lower air temperature in the occupied zone. This allows for improvement of the kitchen indoor air quality without increasing the capital costs of the air conditioning system.

Figure 15 demonstrates a CFD simulation of two kitchens with mixing and displacement ventilation systems. In both simulations the kitchens have the same appliances contributing the same heat load to the space. Supply airflow and temperatures, exhaust airflow through the hoods are the same in both cases. The air is supplied through the typical ceiling diffusers in the mixing system. In the case of the displacement system, air is supplied through specially designed kitchen diffusers (Model AFK) located on the walls. As one can see, the displacement system provides temperatures in the kitchen occupied zone from 73 to 78°F while the mixing system, consuming the same amount of energy as displacement, results in 81...89°F temperatures. This 6°F temperature increase in the kitchen with the mixing air distribution system will result in approximately 10% reduction in productivity (see Figure 1).

Halton H.E.L.P program allows designing kitchen ventilation system for both mixing and displacement ventilation system.

To get more information on Displacement Ventilation System visit www.haltoncompany.com and read about displacement ventilation solutions.

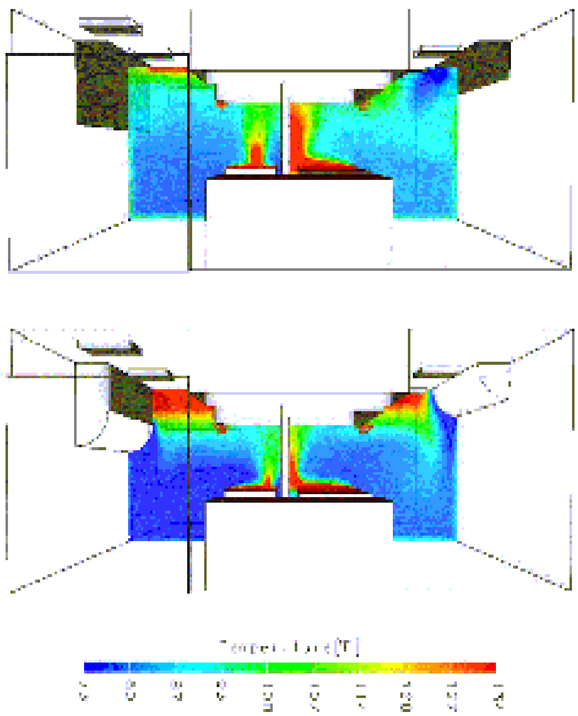


Figure 15 CFD simulation of a kitchen with mixing (top) and displacement (bottom) air distribution system. Air temperatures are shown.

4 Measuring Airflow & Balancing Hoods

For any ventilation system to operate properly in a commercial kitchen, the airflows have to be measured and balanced after the system has been installed to ensure that the design criteria have been met. This chapter provides information on balance the supply and exhaust systems in a commercial kitchen.

4.1 Supply Air Balancing

Balancing is best performed when manufacturers of the equipment are able to provide a certified reference method of measuring airflows, rather than depending on generic measurements of duct flows or other forms of measurement in the field. The general steps for air balancing in restaurants are as follows:

- The exhaust hoods should first be set to their proper flow rates. This should be done with the supply and exhaust fans and cooking equipment on.
- Next, outside air and return flows should be set with all fans operating

When the above steps are complete, the system is properly balanced.

- For new facilities, after several days, belts should be checked and readjusted as necessary
- Once the facility is in operation, the performance of the system should be checked to verify the design is adequate for the actual operation.

Refer to the 1999 ASHRAE HVAC Applications Handbook, Chapter 30 for more information.

4.2 Exhaust air balancing

Halton offers a variety of means for determining the exhaust flow through their Capture-Jet™ hoods. Integral to all Capture-Jet™ hoods is the Test & Balance Port (T.A.B.). These ports are to be used in determining both the exhaust and Capture-Jet™ airflows. Each incremental size of hood has been tested through the range of operable airflows and a curve has been generated showing airflow as a function of pressure drop across the T.A.B. Regardless of duct configuration, the T.A.B. ports will give you an accurate reading of airflow.

Another Halton product, the Equalizer™ Balancing Damper (Model KBD) is designed for use in specialized applications requiring multiple hoods on a single duct or otherwise difficult balancing projects. This product is presented in detail in Section 4.3.

A last resort for measuring exhaust airflows is to use the average face velocity. In lieu of the availability of a KBD or T.A.B. ports a velometer can measure velocity at several points across the filters. Typically you would drop the high and low readings and average the balance. Multiply this number by the filter area to get an idea of the exhaust rate. There should be a minimum of 3 readings (top middle, bottom per 1 foot length of filter area) Readings should be taken approximately 3” away from the filter face and repeated as necessary. The accuracy of this method is not high and should only be used as an estimate.

4.3 Equalizer™ Balancing Damper for Kitchen Hoods

Current codes and standards in the United States do not allow the installation of balancing dampers in kitchen hoods or exhaust ducts. This requirement is dictated by the fact that standard dampers create obstacles for the exhaust air stream to collect grease. Halton Company has developed and obtained UL certification for the Equalizer™, the first in-hood balance device on the market. This damper allows several hoods to be connected to a common exhaust duct and balance each hood to the required exhaust

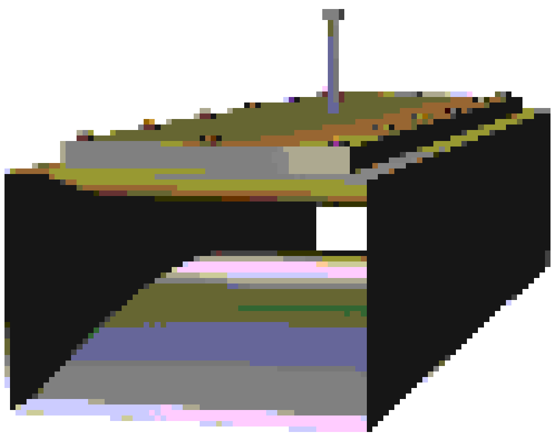


Figure 16 Equalizer™

The Equalizer™ is a balancing damper, airflow measurement device and access panel for duct cleaning – all in one. The airflow is estimated from the measurement chart using the damper adjustment position and pressure drop measured across the measurement taps as inputs.

The Equalizer™ is designed in the shape of rectangular duct with two opposite walls smoothly curved towards each other (see Figure 16). This unique design not only minimizes the noise generated by the airflow damper but also limits grease deposition rates on the walls.

4.4 Differential Pressure Difference Testing

It is important that ventilation system is balanced – total supply airflow for the building is equal to the total exhaust airflow. To assure this differential pressure method is used. By measuring the pressure difference between inside and outside a close approximation of system balance can be achieved.

Closing all doors and windows, with the cooking appliances on, the exhaust fan and supply fans running, check the pressure differential between the inside and outside of the building. This number should not exceed .02 inches of water (NFPA-96-1998, Section 5-3).

5 Fan and Duct Sizing

The NFPA guidelines state that duct sizing is predicated on air volume and velocity. NFPA-96 states a minimum duct velocity of 1500 fpm. Take the volume of air to be moved and divide by the velocity desired. This will give you the square area of the duct. It is recommended when sizing the exhaust duct to size for at least 1800 fpm not to exceed 2200 fpm. This is due to the noise potential for the higher velocities and by sizing for a median velocity; it gives the designer greater flexibility in changing exhaust rates up or down. Ideal duct size is 1 to 1 ratio, trying not to exceed 2:1 whenever possible to minimize static pressure and noise. Radius elbows instead of hard 90°should also be considered for the same reason.

There are two important factors to take into account when selecting the fan: pressure and sound level. When the fan is installed in the duct system, the pressure it creates is used to cover the total duct pressure loss. The airflow of the fan is determined at the point where the fan pressure curve and the system pressure curve intersect.

A common practice is that the fan manufacturers use the static pressure in their literature, therefore, it is adequate just to define the static pressure loss in the ductwork and total airflow to select the fan. Hood and grease extractor manufacturers give the pressure information of these products. The data on frictional and dynamic losses of the duct system can be found in various sources (see Ref 1 and literature from fan manufacturers).

6 Grease Extraction

The convection plume from the cooking operation underneath the hood contains grease that has to be extracted as efficiently as possible. The amount of grease produced by cooking is a function of many variables including: the type of appliance used for cooking, the temperature that food is being cooked at, and the type of food product being cooked.

The purpose of a mechanical grease filter is to twofold: first to provide fire protection by

preventing flames from entering the exhaust hood and ductwork, and secondly to provide a means of removing large grease particles from the exhaust stream. The more grease that can be extracted the longer the exhaust duct and fan stay clean, resulting in better fire safety.
From a practical standpoint, grease filters should be easily cleanable and non-cloggable. If the filter becomes clogged in use, the pressure drop across the filter will increase and the exhaust airflow will be lower than designed.

6.1 What Is Grease?

According to the University of Minnesota (Gerstler, et. al, Ref. 6) grease is comprised of a variety of compounds including solid and/or liquid grease particles, grease and water vapors, and a variety of non-condensable gases including nitrogen oxides, carbon dioxide, and carbon monoxide. The composition of grease becomes more complex to quantify as grease vapors may cool down in the exhaust stream and condense into grease particles. In addition to these compounds, hydrocarbons can also be generated during the cooking process and are defined by several different terminologies including VOC (volatile organic compounds), SVOC (semi-volatile organic compounds), ROC (reactive organic compounds), and many other categories.

6.2 Grease Emissions By Cooking Operation

An ASHRAE research project conducted by the University of Minnesota (see Ref 6) has determined the grease emissions from typical cooking processes. Figure 17 presents total grease emissions for several appliances.

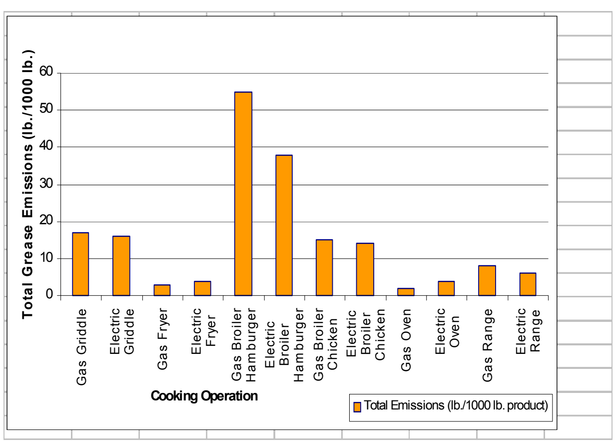


Figure 17 Total Grease Emissions By Appliance Category

Upon observing Figure 17, it appears at first as if the underfired broiler has the highest grease emissions. However when examining the figure closer you see that if a gas or electric broiler is used to cook chicken breasts, the grease emissions are slightly lower than if you cook hamburgers on a gas or electric griddle. This is the reason that we are discussing "cooking operation" and not merely the type of appliance. However, we can say that, for the appliances tested in this study, the largest grease emissions are from underfired broilers cooking burgers while the lowest grease emissions were from the deep-fat fryers. The gas and electric range were used to cook a spaghetti meal consisting of pasta, sauce, and sausage. All of the other appliances cooked a single food product. It is expected that the emissions from solid-fuel (e.g., wood burning) appliances will probably be on the same order of magnitude as under-fired broilers, but in addition to the grease, large quantities of creosote and other combustion by-products may be produced that coat the grease duct. Chinese Woks may have grease emissions well above under-fired broiler levels due to high surface temperature of the Woks combined with the cooking medium utilized for cooking (e.g. peanut oil, kanola oil, etc.) which will tend to produce extreme grease vaporization and heat levels. Table 6 presents the specific foods cooked for the appliances presented in Figure 17 and Figure 18.

Appliance	Food Product
Gas Griddle Electric Griddle	Beef hanburgers, 0.25 lb., 5 in. diameter, 20% fat content
Gas Fryer Electric Fryer	French fried potatoes, par-cooked, frozen shoestring potatoes, 0.25 in. thick with 2.2% fat content
Gas Broiler Electric Broiler	Beef hanburgers, 0.33 lb., 5 in. diameter, 20% fat content
Gas Broiler Electric Broiler	Boneless, skinless chicken breast, frozen, 0.25 lb., 0.5 in. thickness
Gas Oven Electric Oven	Sausage pizza with sausage, textured vegetable protein, mozzarella cheese, and cheese substitute. Each slice was 4x6., 0.314 lb.
Gas Range Electric Range	Two pots of spaghetti noodles, 5.0 lb. dry weight, one pot boiling water, two pots of tomato based spaghetti sauce, 107 oz. Each, Three lb. of link style sausage cooked in a frying pan

Table 6 Description of Food Cooked On Each Appliance

The components of grease were discussed earlier and a breakdown of the grease emissions into the particulate and vapor phases is shown in Figure 18.

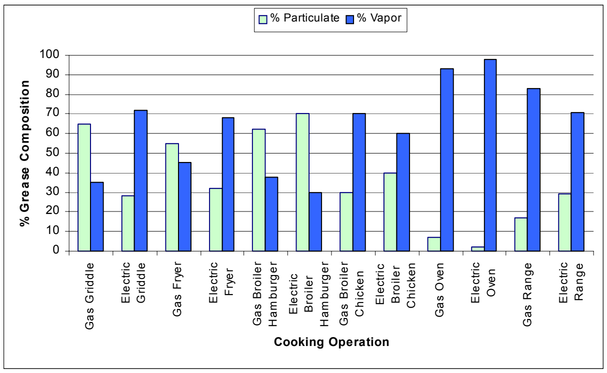


Figure 18 Particulate and Vapor Grease By Appliance Category

Upon examining Figure 18, it becomes apparent that the griddles, fryers, and broilers all have a significant amount of grease emissions that are composed of particulate matter while the ovens and range tops are emitting mainly grease vapor. If you combine the data in Figure 17 with the earlier data in Figure 18 it becomes evident that the broilers have the largest amount of particulate matter to remove from the exhaust stream.

The final piece of information that is important for grease extraction is the size distribution of the grease particles from the different cooking processes, presented in Figure 19.

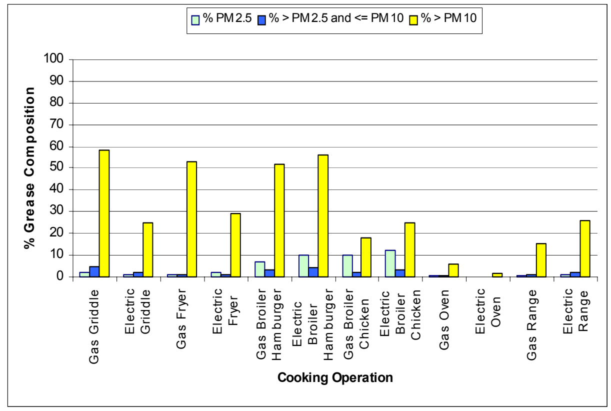


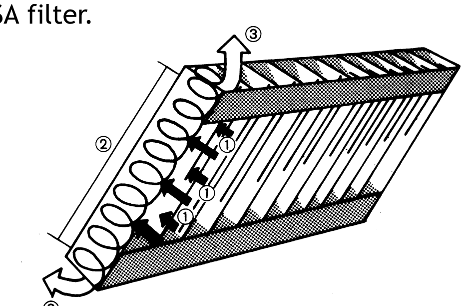
Figure 19 Particle Size Distribution by Cooking Process

It can be observed from Figure 19 that, on a mass basis, cooking processes tend to produce particles that are 10 microns and larger. However, the broilers produce significant amounts of grease particles that are 2.5 microns and smaller (typically referred to as PM 2.5) regardless of the food being cooked on the broiler.

6.3 Cyclonic Grease Extraction

One non-cloggable design of a baffle type grease extractor is a "cyclone.' The extractor is constructed of multiple cyclones that remove grease from the air stream with the aid of centrifugal force.

Figure 20 presents Halton's KSA grease filter design. You can see the cyclonic action inside the KSA filter.



1. Air enters through a slot in the filter face
2. Air spins through the filter impinging grease on the filter walls

Figure 20 Halton KSA Filter

Figure 21 presents the extraction efficiency curve for Halton's KSA filter for two different pressure drops across the filter.

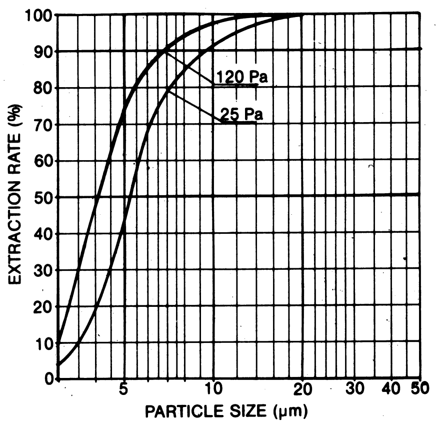


Figure 21 Grease Extraction Efficiency Curves for KSA Filter

Mechanical grease filters quickly lose grease removal effectiveness as the particulate size drops below 6 microns depending on the pressure drop across the filters. As can be seen in Figure 21, the grease removal efficiency of mechanical filters when encountering PM 2.5 is 10% or less.

6.4 EPA Method 5

The most commonly used method to quantify the mass of grease that bypasses a filtering device is to use the U.S. Environmental Protection Agency's (EPA) Method 5 test (See Ref. 9). Several derivatives of this method have been implemented by testing agencies around the country, the most recognized of which is the method used by the South Coast Air Quality Management District (SCAQMD) in Los Angeles. These EPA Method 5 test measures the particulate and vapor mass that bypasses the filter while the SCAQMD protocol adds the measurement of volatile organic compounds (VOC) to the basic procedure. The basic test setup is shown below in Figure 22.

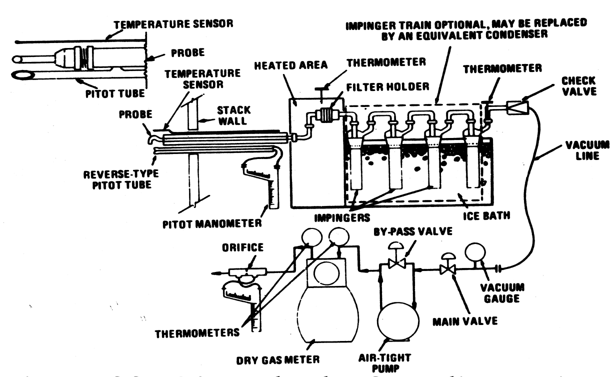


Figure 22 EPA Method 5 Sampling Train

In application the probe is places inside the exhaust duct and the temperature of the probe is allowed to stabilize. The cooking process is then started and the grease particles and vapor are entrained into the sampling train. Inside the filter holder is a 0.3 micron glass fiber filter that removes the particulate matter from the entrained air, or alternatively a particle size impactor may be used at this location to further separate the grease particles into discrete size ranges. Next, the entrained exhaust stream enters a series of impingers, placed in an ice bath to cool them, and condensable vapors are collected at this location. Finally, volatile organic compounds may be analyzed using a hydrocarbon analyzer on the remaining entrained exhaust air.

The results of this test method are generated by performing a mass analysis on the glass fiber filter(s) and vapors collected in the impingers. Prior to testing, the filter is desiccated till dry and pre-weighed and then desiccated and post-weighed after testing is completed. This difference in mass is the weight of particulate matter that was produced by the cooking process and is normalized to the amount of food that was cooked during the sampling period.

The impingers are cleaned prior to testing and rinsed with Acetone after testing is completed and are placed in pre-weighed dishes to evaporate. After the evaporation is completed, the amount of mass gain in the dishes is equal to the mass of condensable vapors emitted by the cooking process. Once again, this is typically normalized to the amount of food cooked during the sampling period.

7 Glossary of terms

C & C – capture and containment
CFD – computational Fluid Dynamics
Hood Capture Efficiency - the ability of the kitchen hood to provide sufficient C&C at minimum exhaust flow rate
HVAC – Heating, Ventilation, Air Conditioning
Occupied Zone – lower part of the room where people are, typically 5…6 feet from floor
Thermal Plume – thermal air currents created by the surfaces which temperature is different from the surrounding air temperature. In kitchen environment, for example – warm air rising from hot surfaces of cooking equipment.

1 References

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