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A Realistic Evaluation of Kitchen Ventilation Hood Designs

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ABSTRACT

Proper application of kitchen ventilation hood designs has been difficult for several reasons, including:

1. Codes vary widely. Some areas require little or no testing and impose no restrictions on hood designs. Other areas require hoods to meet the requirements of several code agencies and use excessive quantities of exhaust and supply air.

2. Cooking equipment served by ventilation hoods varies greatly in its heat, grease, and smoke output.

3. Exaggerated claims and scientifically unfounded designs and theories have caused many architects and engineers to specify equipment based on unrealistic expectations.

4. No uniformly accepted method of testing hood performance has been established.

This paper examines the performance of the most common hood designs in an effort to determine the best application and credibility of each design. It gives results of field tests on two hood designs. The paper also examines other factors that contribute to efficient operation of kitchen ventilation equipment.

INTRODUCTION

Determining the quantity of exhaust that will adequately ventilate the contaminants produced by a line of cooking equipment can be a difficult procedure. There are many factors to be considered, including the amount of heat, grease, and smoke produced by the cooking equipment; code requirements; room drafts; HVAC system design; and hood design. Several methods of determining the proper level of exhaust for cooking equipment ventilation hoods have been developed. The three most common methods will be briefly discussed.

The best known method for determining exhaust for ventilation hoods is set forth in NFPA 96 (NFPA 1980). The method presented in this standard bases its calculation on maintaining a given velocity of 100 to 150 fpm (0.508 to 0.762 m/s) into the hood capture area. The exhaust quantities predicted by this method prove to be far greater than what is actually necessary in almost every case.

While using the exhaust quantities calculated by this procedure will ensure capture, there are drawbacks to using this method. By exhausting large quantities of air from the kitchen, a great deal of conditioned room air is lost from the building. Therefore, large quantities of make-up air (MUA) must be brought back into the building. Depending on the geographical location of the building, the cost of tempering the MUA could be quite expensive. To help alleviate this cost, the short-circuit-type hood was developed. This type of hood delivers untempered MUA into the capture area, where it can be exhausted without affecting the kitchen environment.

Other hood designs were developed with various MUA diffuser locations and designs to help reduce the amount of tempered MUA needed, each with its own benefits and drawbacks. The use of compensating hoods to meet exhaust quantities required by code and reduce the amount of tempered MUA required will be discussed in detail later in the paper.

A more accurate method for determining the exhaust required to ventilate a particular line of cooking equipment is by estimating the amount of heated air produced by each piece of equipment. An example of this method is shown in a ventilation hood manufacturer's application guideline (GFC 1981). The air stream rising from the equipment can be approximated most closely by treating the process as natural convection from a hot body. The grease and smoke created during the cooking process are entrained in the rising heated air stream and are carried up to the hood by the natural buoyancy of the heated air (Hatch and Barron-Oronzco 1957). Therefore, if the heated air stream produced by the cooking equipment is captured, all the grease and smoke produced will also be exhausted.

To make calculations easier and because of the large variation in design, size, and heat output of cooking equipment, this method groups equipment into classes. A vertical updraft velocity is assigned to each class of equipment based on the heat rise predicted from the equipment. This velocity is multiplied by the area of the cooking surface to calculate an exhaust cfm. After calculating the exhaust needed to ventilate the equipment by this procedure, an additional amount of exhaust must be added to ensure an adequate velocity into the capture area in areas covered by the hood where there is no equipment to provide any heat rise into the canopy. This additional exhaust will con

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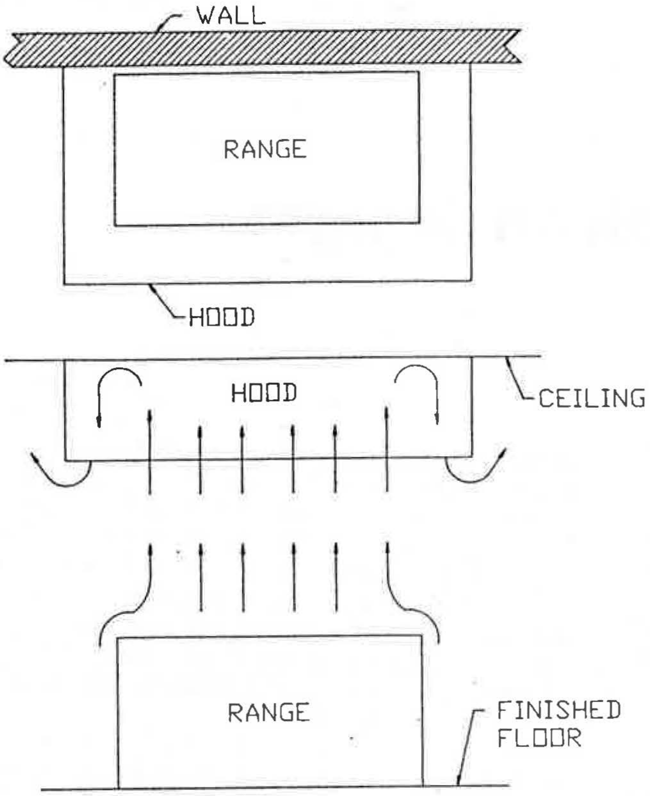


THE DRAWING ABOVE SHOWS HOW CONTAMINANTS TRY TO ESCAPE FROM THE HOOD IN AREAS WHERE THE HOOD OVERLAPS THE COOKING EQUIPMENT WHEN THE EXHAUST IS NOT SUFFICIENT TO REMOVE ALL CONTAMINANTS

Figure 1 *Typical contaminant escape*

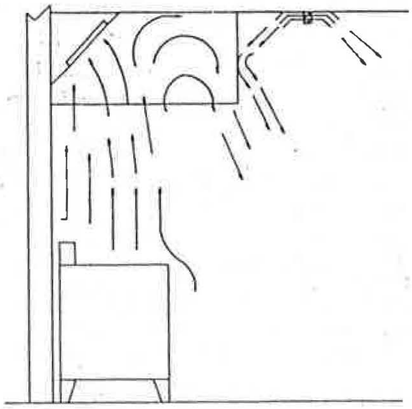
tain the surges of heat produced by the cooking process as they fill up the hood and try to escape from the capture area (Figure 1).

While this method of predicting exhaust gives reasonable results, it has several drawbacks. The method only approximates the heat produced by the equipment; the accuracy of this method depends on how well the equipment covered fits into the class to which it is assigned. This method of exhaust calculation can be quite time consuming, especially when information on the cooking equipment is not readily available. In some cases, due to short lead times and lack of information, the precise equipment layout is not available to the company or individual determining the necessary level of exhaust. Another drawback of this method is that it is not recognized by any of the applicable codes as an acceptable method of determining the proper exhaust for a ventilation hood.

Another method employed to size ventilation hood exhaust is the hood's UL classification or listing. Underwriters Laboratories (UL) tests ventilation hoods with a standardized grease and smoke test designed to duplicate actual cooking conditions. A 3 ft by 2 ft (0.914 m by 0.610 m) electric 15.5 kW grill is set at maximum heat and loaded with 1/3 lb (0.151 kg) burgers made of 70% lean beef. The burgers are cooked for five minutes, flipped, and cooked for five minutes more. If any grease or smoke escapes from the hood, it fails the test and the hood is retested at a higher exhaust cfm. The exhaust cfm is measured before each test by performing a duct traverse. The test is performed on a 4 ft (1.22 m) hood and the longest length hood to be served by one exhaust duct (typically 10 ft to 12 ft [3.05 to 3.66 m]). The grill is centered under the 4 ft (1.22 m) hood and positioned at the end of the longer hood. The grill is located 6 in (0.152 m) off the wall and 6 in (0.152 m) from the end of the hood during the test. Similar grill placement is used in island hood tests, except the back of the grill is located 6 in (0.152 m) from the centerline of the hood. The hood's performance in this test is recorded in terms of exhaust cfm per linear foot of hood. This rating is considered valid for any width of hood as long as its width is equal to or greater than the width of the hood used during the test.

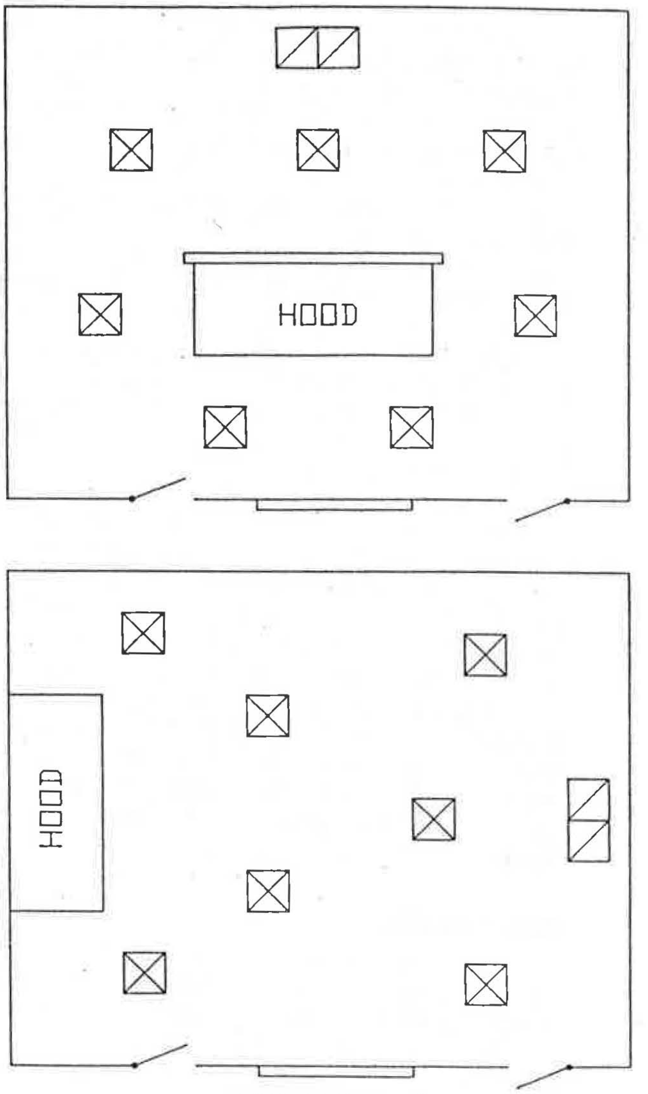
This method of calculating exhaust has advantages and disadvantages. It is easy to calculate the exhaust cfm needed by this method. However, because the method is based on an exhaust cfm measured in a test environment and the cooking equipment used in the test does not produce as much heat and smoke as some other types of equipment (i.e., charbroilers), the exhaust cfm predicted may be less than what is actually required. The UL classification and listing both state that the level of exhaust specified by the test is a minimum value. In compensating hoods, the supply cfm given in the UL listing and classification is specified as a maximum. In some cases the UL-specified minimum and maximum values will be applicable; however, strong room drafts and/or high heat equipment will require ventilation hoods to use higher levels of exhaust and less supply air. While the values given by the UL listing and classification are not always applicable, they provide a reference point from which to evaluate different hood designs relative to each other. NFPA 96, the Uniform Mechanical Code, and other nationally recognized code agencies allow the exhaust and supply values stated by a hood's UL listing and/or classification to supersede the requirements stated by their code, as long as the hood is installed in accordance with the terms of the hood's listing and the manufacturer's installation instructions. The use of UL-specified minimum exhaust values and maximum supply values over all types of cooking equipment and in all types of kitchen environments has caused specification of ventilation equipment based on unrealistic expectations. This problem will be discussed in more detail later in this paper.

Local code officials have the final say in determining the acceptable level of exhaust and supply air for ventilation hoods installed in areas under their jurisdiction. Most code officials accept the standards set forth by the NFPA and the Uniform Mechanical Code. As previously stated, these codes recognize UL listed and classified hoods as acceptable when set at the levels specified by the UL test reports. However, some regions of the country require cooking equipment ventilation hoods to meet criteria set forth by the city, county, or state. In certain areas, such as Las Vegas, NV, and Irving, TX, the local codes prohibit the use of short-circuit-type hoods. Some areas have established their own method for determining exhaust requirements



THE DRAWING SHOWS HOW AN HVAC DIFFUSER CAN CREATE AN AIR CURTAIN ALONG THE FACE OF A VENTILATION HOOD CAUSING CONTAMINANTS TO BE DRAWN OUT OF THE HOOD

Figure 2 *Improperly placed diffuser*



SUPPLY DIFFUSER – ☒
RETURN GRILLE – ▨

EXAMPLES OF HVAC DIFFUSER AND RETURN GRILLE ARRANGEMENT THAT DO NOT ADVERSELY AFFECT THE PERFORMANCE OF THE VENTILATION HOOD

Figure 3 *Proper HVAC grille placement*

and require a performance test of the hood. For these reasons, there is no clear-cut method for determining the exhaust requirement for ventilation hoods that will be universally acceptable.

A major cause of unacceptable hood performance is the lack of coordination between the HVAC system and the ventilation hood system. Many times, the net air loss associated with the ventilation system is not considered when sizing the HVAC system outside air requirements. The air lost from the kitchen must be replaced for the ventilation hood to work most efficiently. If the hood is operated in an environment with high negative pressure, the negative pressure created in the hood's capture area must compete with the negative pressure in the room to capture the contaminants. A large negative pressure in a building will cause room drafts to change when a door or window is opened. As room drafts change, there is a high probability the hood's capture ability will be adversely affected. Insects, dust, and other unwanted debris and odors can be drawn into the kitchen when a door or window is opened if the kitchen has a high negative pressure. While the kitchen should be negative in pressure with respect to the dining room to keep cooking odors in the kitchen, the negative pressure at the back door of the kitchen should never exceed 0.02 in of water (4.98 Pa).

Another factor to be considered when designing HVAC systems for kitchens is the style and placement of diffuser and return grilles. Diffusers should dump the conditioned air into the kitchen and allow the drafts created by the ventilation hoods to move air throughout the kitchen. When diffusers throw the air into the kitchen, the drafts created adversely affect the hood's performance. A high-velocity stream of air shooting out of a diffuser creates a pressure drop and draws the surrounding air into the stream. Because this air will be blowing down into the room, it can only act against the natural rise of contaminants into the hood. End panels are an excellent means of combating room drafts adversely affecting hood capture. By decreasing the perimeter of the hood through which air can be drawn into the hood, the draft across the front edge of the hood is increased and the hood's ability to compete with room drafts is increased. End panels will block room drafts directed along the length of the hood that would normally blow smoke and grease out from under the hood before they enter the hood's capture area. The HVAC diffusers cannot be placed close to the face of the hood or the air discharged will bounce off the hood face and create an air curtain, drawing smoke and grease to the front edge of the hood and away from the filters (Figure 2).

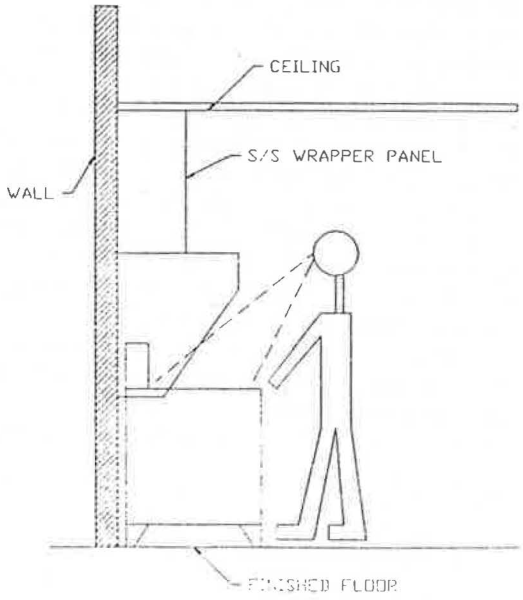
The best type of diffuser to use is a perforated plate-type design. Any diffuser that creates drafts of less than 50 fpm (0.254 m/s) at 6 ft (1.83 m) A.F.F. will be ideal. The diffusers should be placed along the cooking line at least 24 in (0.610 m) from the front face of the hood. Return grilles should be placed as far away from the hood as possible. A return grille drawing 2100 cfm (991.2 L/s) from the kitchen has the same exhaust as a low-cfm exhaust hood up to 14 ft (4.27 m) long. (Some manufacturers have exhaust-only canopy hoods UL-listed at exhaust cfm requirements as low as 150 cfm [70.8 L/s] per linear foot of hood.) Because the drafts created by return grilles are so strong, it is best to have a wall separating the return grilles from the ventilation hood when possible. Another way to limit the effect that return grilles have on the hood is by placing several diffusers between the hood and the return grille (Figure 3). This should be done even if there is a wall between the hood and the return grille. The air discharged by the diffusers breaks up the drafts created by the return grille. This essentially hides the effects of the return grille from the hood. When a building has the proper amount of MUA to alleviate the negative pressure caused by the hood system and the HVAC diffusers and return grilles are properly placed in the kitchen, the ventilation hood will perform at its maximum potential and efficiency.

The hood design is another major factor affecting the amount of exhaust needed to adequately ventilate a line of cooking equipment. While the primary purpose of ventilation hoods is to exhaust contaminants produced by the cooking process, the hood's effect on the kitchen environment and cooking process while performing this test can also be a major consideration when choosing a hood. By analyzing the airflow patterns created by various hood designs and testing the performance of these designs under various conditions, a more educated choice can be made when selecting a hood to satisfy the needs of a particular cooking application and/or the concerns of the consumer purchasing the ventilation system.

HOOD DESIGN

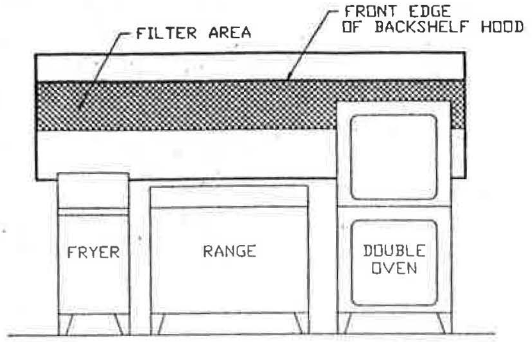
There are two basic types of ventilation hoods—canopy and low proximity or backshelf hoods. The canopy hood is typically mounted 78 in (1.98 m) A.F.F. and is sized to overhang the cooking equipment. Most codes require the hood to overhang the cooking equipment by 6 in (0.152 m) on each end and along the front edge. The side overhang requirement can be eliminated if the end of the hood is mounted against a wall or if end panels are used. Some areas require more overhang, particularly when the hood covers charbroilers or other high-heat-producing equipment. The canopy hood is designed to collect the heat, grease, and smoke as they rise off the cooking equipment and to contain these contaminants in the capture area of the hood until they can be exhausted. Because the cooking process produces surges of heat, contaminants will try to roll out of the capture area in regions along the perimeter of the hood where it overhangs the equipment (Figures 1 and 1a). In this region, there is no rising air stream to lift the contaminants into the hood. Therefore, the hood must use make-up air or additional exhaust to create a draft along the hood's perimeter to contain this rollout. The different methods of introducing MUA will be discussed as each canopy hood design is analyzed. A disadvantage of the canopy hood is the drastic effect room drafts have on this type of hood's performance. Typically, the cooking equipment is 3 ft to 4 ft (0.914 to 1.219 m) below the hood, allowing room drafts to blow contaminants out from under the hood before they rise into the capture area.

The backshelf hood is designed to hang very low to the cooking equipment and create a strong draft over the cooking surface. This hood is sized to underhang the equipment; therefore, the draft created over the cooking surface must be strong enough to bring the contaminants into the hood before they rise above the hood's front edge. The backshelf hood must underhang the equipment so the cook can see what he or she is doing without stooping down (Figure 4). The draft across the cooking surface necessary to draw contaminants into the backshelf hood and capture them is typically 50 to 100 fpm (0.254 to 0.508 m/s). Because the backshelf hood sits so low to the equipment, a significant draft can be created using a relatively low exhaust cfm. For this reason, the hanging height of the backshelf is particularly critical to its performance and the equipment height must be known to properly install the hood. The strong draft created by the backshelf hood and its close proximity to the cooking equipment make it less susceptible to room drafts. If high-heat-producing equipment is covered, the contaminants produced will rise too quickly to be drawn into the hood; therefore, charbroilers and other high-heat cooking equipment cannot be used with the backshelf hood. The use of high-heat equipment under backshelf hoods will cause grease to burn on the hood, producing discoloration, and will increase the chance of an inadvertent fire system actuation due to a fusible link failure. The backshelf hood requires a stainless steel wrapper panel or shroud to enclose the ductwork from the hood to the ceiling; thus, the ceiling height and hanging height must be known to adequately size these panels. While this type of hood requires much more detailed information to be properly applied, the backshelf hood can perform at lower net exhaust quantities than canopy hoods used in the same applications. For example, some backshelf hoods are UL-classified at exhaust ratings as low as 114 cfm (53.8 L/s) per linear foot of hood.



BACKSHELF HOODS ARE HUNG CLOSE TO THE EQUIPMENT; THEREFORE
THE HOOD MUST UNDERHANG THE EQUIPMENT TO ALLOW THE COOK
TO SEE THE ENTIRE COOKING SURFACE

Figure 4 *Backshelf hood application*



THE WIDE VARIATION IN EQUIPMENT HEIGHT INCREASES THE AREA BETWEEN THE BACKSHELF HOOD AND THE COOKING SURFACE

USE OF A BACKSHELF HOOD IN THIS APPLICATION DECREASES THE VELOCITY OF THE DRAFT ACROSS THE EQUIPMENT CREATED AND LOWERS THE PERFORMANCE OF THE HOOD

Figure 5 *Backshelf application limitations*

while the lowest canopy hood UL classification is 149 cfm (70.3 L/s) exhaust per linear foot of hood. Lower net exhaust always translates into savings by using smaller fans, bringing in less tempered MUA, and exhausting less conditioned air.

Exhaust-Only Hoods

The exhaust-only hood is the simplest type of ventilation hood. Its performance is based almost entirely on the airflow pattern it creates when drawing exhaust into the capture area. The exhaust is drawn through a set of grease filters or a high-velocity slot to extract the grease from the heated air. As contaminants rise off the equipment and enter the hood, they continue to rise to the highest point possible. The exhaust filters or slot should be located high in the capture area to exhaust the contaminants as they collect in this area. The airflow created by the exhaust should be aimed along the hood's perimeter to aid in rollout recapture, as previously discussed. If the exhaust opening is located and aimed properly, the hood will exhaust all the contaminated air before exhausting any conditioned room air and can be balanced to perform at peak efficiency. If grease filters are used, the filter area must be sized to create filter face velocities within the parameters suggested by the filter manufacturer when the hood is operated at the proper level of exhaust. If the filter face velocity is too high or too low, the filter will not extract grease at its designed efficiency. Some hoods use high-velocity baffles or slots to extract grease and aim the exhaust more effectively. The slot design is particularly effective on backshelf hoods since a high-velocity draft is crucial to their performance.

There are several advantages to using exhaust-only ventilation hoods. They are inexpensive and relatively simple to install and balance. They require no MUA fans or supply air ductwork. Canopy exhaust-only hoods are particularly good for use over high-heat equipment due to the high net exhaust needed to contain the rapidly rising, turbulent airflow created by this equipment. Backshelf exhaust-only hoods are particularly useful when covering light to medium cooking loads, due to their lower net exhaust requirements as compared to canopy exhaust-only hoods covering the same equipment. On small backshelf hoods, the net exhaust can be low enough to eliminate the need for MUA entirely. However, if the cooking equipment covered varies greatly in height or if the equipment stands high off the floor, such as an oven, the backshelf hood should not be used (Figure 5).

Make-Up Air/Compensating Hoods

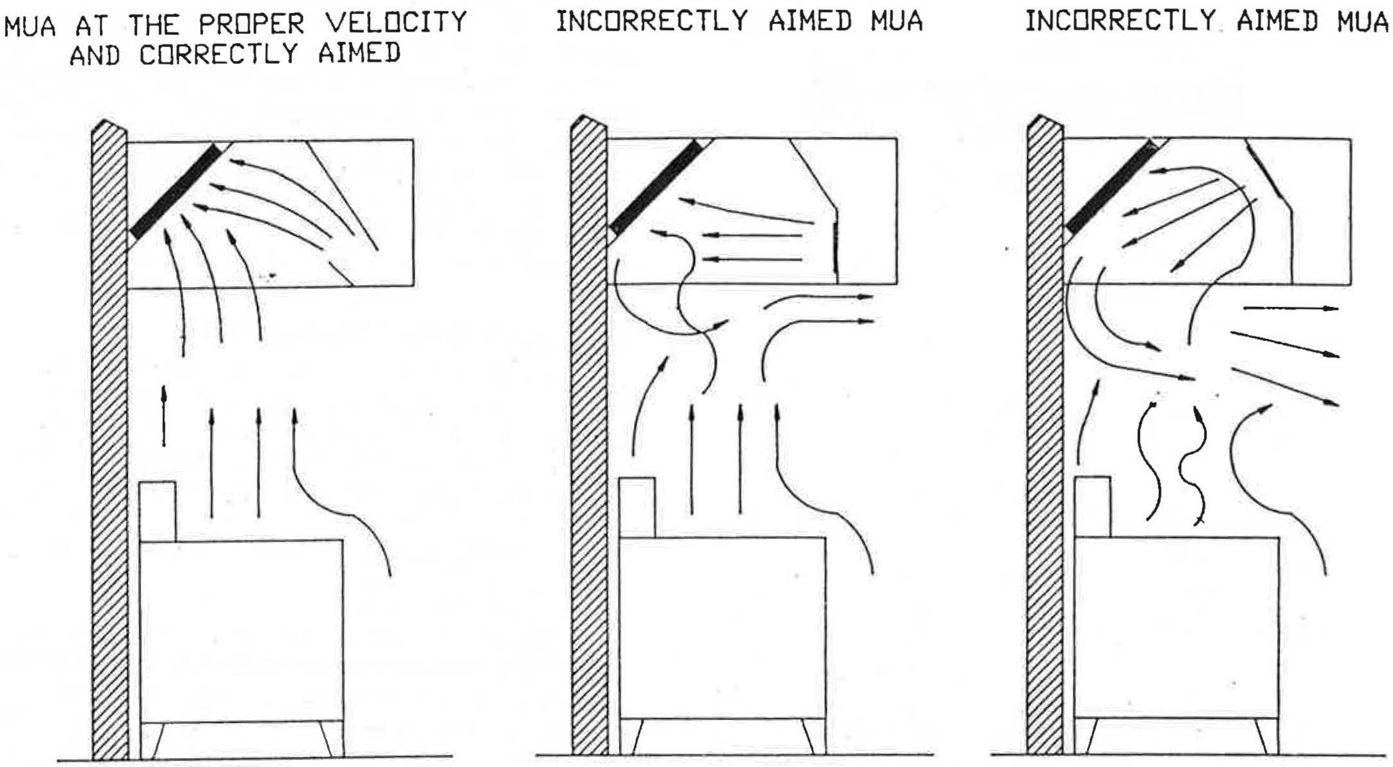
The compensating hood is designed to decrease the net air loss from the kitchen created by the ventilation hood. The manner in which the make-up air is returned through the hood determines the benefits and drawbacks of each design. There are four basic types of make-up air hoods:

1. Short Circuit
2. Front Discharge
3. Down Discharge
4. Back Discharge

These four types of MUA return systems have also been combined to increase the amount of MUA that can be brought back into the kitchen through the ventilation hood. The most important fact to keep in mind when analyzing compensating hoods is that the MUA discharged by the hood must act to promote the natural rise of contaminants off the equipment into the exhaust stream and/or to contain the contaminants inside the capture area. If the MUA acts against the natural flow of exhaust in the hood, the amount of exhaust needed will increase and the make-up air will be of no benefit in lowering the net exhaust removed from the kitchen. This paper will only analyze wall-type compensating hoods; however, the same principles discussed for wall hoods will be applicable to island hoods.

The short-circuit-type hood was created to combat the excessive exhaust requirements of many codes (i.e., NFPA 96). By introducing MUA into the hood's capture area, the MUA can be exhausted before entering the room and the net exhaust of the hood can be lowered while meeting the exhaust required by code. To maximize the performance of this type of hood, the MUA must be diffused into the capture area so as to direct the rising contaminants into the exhaust filter area. In properly designed short-circuit hoods, the air stream created by the MUA draws contaminants to itself and leads them to the exhaust filters. If the MUA is discharged horizontally across the width of the hood, it can form a barrier between the contaminants and the filter area and will blow contaminants out into the room as MUA bounces off the wall. If the MUA is discharged at a 90° angle to the filter area, it will simply wash the contaminants from the filter area and push them out into the room (Figure 6). This type of MUA arrangement is particularly common on backshelf hoods utilizing a front discharge short-circuit design (Figure 7).

The velocity of the MUA impinging on the exhaust filters typically must not exceed the filter face velocity or the MUA will bounce off the filters and push contaminants away from the filter area. The MUA slot must be sized correctly to allow the MUA to enter the capture area at the proper speed, while supplying the necessary quantity of


MUA AT THE PROPER VELOCITY AND CORRECTLY AIMED

INCORRECTLY AIMED MUA

INCORRECTLY AIMED MUA

Figure 6 *Airflow patterns created by various short circuit hood designs*

MUA. As with the exhaust-only hood, the filter area should be located high in the hood to exhaust contaminants as they collect there. This is true of all canopy-style hoods. The short-circuit hood must be carefully balanced to work properly. The MUA and exhaust will not be spread evenly throughout the hood; the MUA will tend to spread to the ends of the hood and the exhaust will be higher near the ducts. Therefore, when balancing the hood, the exhaust and MUA quantities must be adjusted to allow the areas of the hood with the highest supply and lowest exhaust to work properly. The uneven spread of exhaust and supply air is a common problem with all hood models and the degree of the problem varies with the hood's MUA and exhaust plenum size and design. The design of the ductwork is another factor causing an uneven distribution of MUA and exhaust in ventilation hoods.

Because air density will change as the weather changes, the hood's capture could be affected by the MUA density; the hood will work the worst when the MUA is cold and dense. The cold MUA will tend to drop and work against the rising contaminants entering the hood. Therefore, the short-circuit hood should be balanced while the weather is cold to work properly year-round. Because the short-circuit hood produces a negative pressure, the net exhaust removed by this hood must be replaced through the HVAC system or through some other type of MUA system. Failure to account for the net exhaust removed by the short-circuit-type hood is one of the most common problems when the ventilation system is being planned.

The next type of compensating hood to be discussed is the front discharge hood. When make-up air is discharged through the hood's face, it enters the kitchen environment and typically must be tempered. In air-conditioned kitchens, the best design for this style of hood dumps the MUA in the region in front of the hood, where it can be captured by the hood and exhausted without allowing the MUA to spread throughout the room. Some hood manufacturers use a perforated plate over the entire hood face to deliver the MUA as slowly as possible into the kitchen. While this design has advantages, recent interpretations in NFPA 96 will soon require the use of fire dampers in face grilles, which could make this product extremely difficult (or impossible) to manufacture. In kitchens without air conditioning, the face grille should discharge at higher velocities to help supplement air movement in the kitchen. As long as the face grille does not create any strong drafts along the face of the hood that would act to draw contaminants into the room and the exhaust is adequate, this design will always work. This style of hood can replace up to 100% of the exhaust air it removes. However, the MUA will typically have to be tempered, which could prove to be costly.

The air-curtain-type compensating hood discharges air along the perimeter of the hood in a downward stream. When properly balanced, the MUA pushes contaminants trying to roll out of the hood back into the air stream rising off the equipment, where they can be exhausted. When the MUA discharge velocity is too high, it blows down on the rising contaminants and increases the level of exhaust needed to remove them from the kitchen. The critical velocity for the air curtain will vary depending on the heat rise generated by the equipment, but typically is between 100 to 200 fpm (0.508 to 1.016 m/s). If the air curtain im-

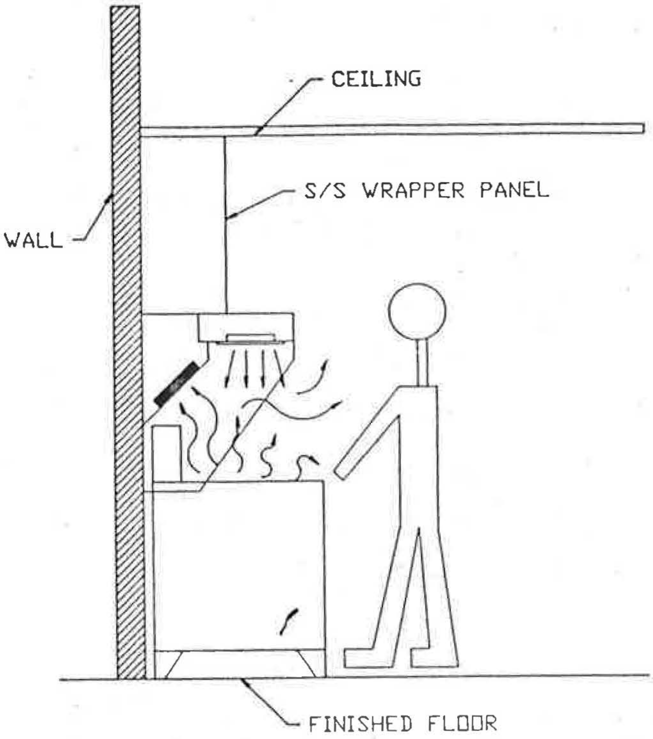


Figure 7 *Airflow pattern created by an improperly designed and balanced front discharge compensating backshelf hood*

pinges on the cooking equipment, it may cause the cooking surface to heat unevenly, blow out pilot lights, or cause food to cook unevenly. As with the short-circuit hood, the MUA grille or slot should be sized to allow the MUA to discharge at an acceptable speed, while supplying the correct quantity of MUA. If the MUA is discharged straight down or out of the hood, contaminants will be drawn to this air stream and out of the hood (Figure 8).

The air curtain design is also used in conjunction with short-circuit and face discharge compensating hoods. On short-circuit hoods, the air curtain design does help the hood's performance if balanced properly and can provide some heat relief to cooks. The amount of air that can be discharged through the air curtain in this application is very low and this MUA must be tempered. The air curtain works better when used in conjunction with a face discharge compensating hood. The MUA discharged through the air curtain diffuser will require the same amount of tempering as the MUA discharged through the face grille; therefore, the same MUA unit can supply air to both the face and air curtain grilles. The air curtain will also act as a shield to hide any air flows created by the face grille that might try to draw contaminated air from the capture area. The major benefit of the air curtain design is the heat relief provided to the cooks by blowing air directly on them; however, this benefit is derived only when the MUA is correctly tempered.

The back-discharge-type compensating hood is the newest type of MUA hood (Figure 9). This design is used mostly in conjunction with low-cfm, exhaust-only hoods. This is typically accomplished by mounting a MUA plenum behind the hood to distribute air behind the cooking equipment. By discharging the air on the floor, it is less noticeable to the cook because it is not impinging on his or her exposed skin. This MUA system also allows the HVAC diffusers to spread conditioned air throughout the kitchen as they were originally intended. Face-grille-type MUA hoods will affect the air flow patterns created by HVAC diffusers in the

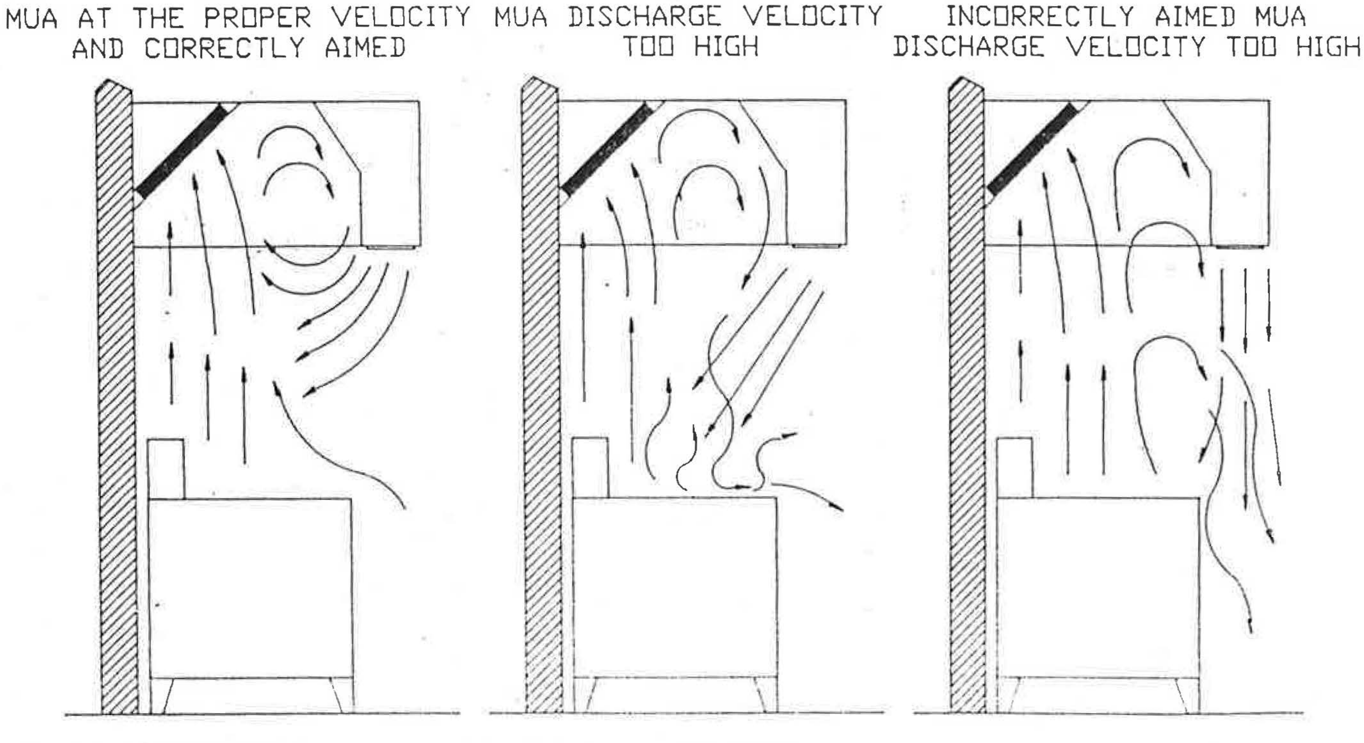


Figure 8 *Airflow patterns created by various air curtain design compensating hoods*

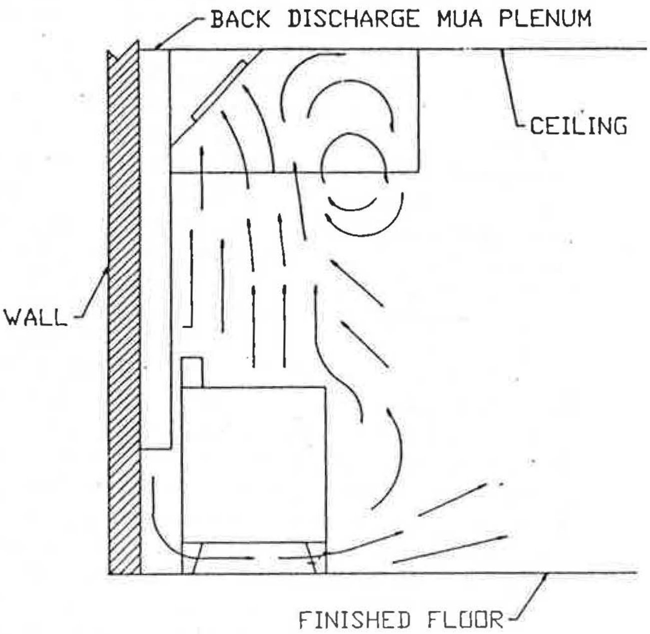


Figure 9 *Airflow pattern created by typical canopy type back discharge compensating hood*

kitchen. Because the back discharge MUA design is typically incorporated with low-cfm exhaust hoods, the amount of MUA that must be discharged into the kitchen using this design is low. The back discharge hood is particularly good in warm environments where discharging warm air through a face-grille-type compensating hood would work against the effects of any air-conditioning supplied to the kitchen. Another benefit to the back discharge compensating hood is that its balance is not crucial to its performance and it can provide up to 100% MUA. The back MUA plenum also serves as a backsplash and a standoff for the hood.

All the hood designs discussed have advantages and disadvantages. When applied properly, each hood design can provide excellent service. It is difficult to test all the hood designs under identical conditions without building a test kitchen and carefully controlling the room drafts and building pressure. In an effort to see if capture performance can be increased by using MUA to contain or direct contaminated air, two compensating hood designs were tested with various levels of MUA. The paper has analyzed hood designs from a qualitative viewpoint up to now; the test data will provide quantitative results of the capture performance of particular hood designs. The results of each test are analyzed separately.

The following equipment was used to conduct the tests—an electronic micromanometer, a rotating vane anemometer, and smoke test candles. The micromanometer was used to traverse the ductwork to arrive at cfm values. The anemometer was used to measure room drafts and grille and slot discharge velocities. The smoke candles were placed centrally on each piece of equipment during the tests and were allowed to discharge completely. All testing was performed with the cooking equipment at operating temperature.

Test Data—Experiment One

The first hood tested was an air-curtain-type compensating island-style hood located at a high school. The following data were gathered concerning the installation:

Hood Dimensions.

Outside Dimensions	Capture Area
12 ft 10 in length (3.91 m)	11 ft 10 in length (3.61 m)
9 ft 10 in width (3.00 m)	8 ft width (2.44 m)
32 in height (0.81 m)	28 in height (0.71 m)

MUA Slot Design. A 5¾ in (0.146 m) wide slot directed toward the floor extending around the perimeter of the hood. No louvers or grilles. A perforated plate was positioned in the slot approximately 6 in (0.152 m) from the lower edge of the hood.

Filtration. Twelve 20 in by 20 in (0.508 m by 0.508 m) mesh filters in V-bank configuration.

Cooking Equipment and Dimensions of its Heated Surfaces.

1. Tilt skillet—14.3 kW—24 in by 42 in (0.610 m by 1.067 m)
2. Steam kettle—32.4 kW—30 in diameter (0.762 m)
3. Three convection steamers—211/2 in by 29 in (0.546 m by 0.737 m) (power output not marked on equipment)
4. Electric fryer—22 kW—13 in by 221/2 in (0.330 m by 0.902 m)
5. Two convection ovens—22 kW—38 in by 37 in (0.965 m by 0.940 m)
6. Two convection ovens—22 kW—38 in by 37 in (0.965 m by 0.940 m)

Building Pressure. Front door—0.02 in water (4.98 Pa) negative. Back door—0.01 in water (2.49 Pa) negative

Pertinent Information.

1. Height from cooking surface to lower edge of the hood was 43 in (1.092 m).
2. Hood hanging height was 78 in (1.981 m) A.F.F.
3. Hood overhang was sufficient except over the convection steamers, which had only 3 in (0.076 m) overhang at the right side and front edge of the hood. All other equipment had at least 6 in (0.152 m) of overhang.
4. A 19 in by 38 in (0.483 m by 0.965 m) sidewall air-conditioning diffuser was located approximately 4 ft (1.22 m) from the left end of the hood, causing a 300 to 120 fpm (1.524 to 0.610 m/s) breeze along the left edge of the hood, directed as shown in Figure 2.

Test Data—Experiment Two

The second hood tested was a short-circuit compensating wall-style hood located at a restaurant in a shopping center in Raleigh, NC. The following data were gathered concerning this installation:

Hood Dimensions.

Outside Dimensions	Capture Area
11 ft 8 in length (3.556 m)	11 ft 8 in length (3.556 m)
48 in width (1.219 m)	42 in width (1.067 m)
24 in height (0.610 m)	24 in height (0.610 m)

MUA Slot Design. A 3½ in (0.089 m) wide slot was directed at the filters. No louvers or grilles. A perforated plate was positioned in the MUA plenum approximately 6 in (0.152 m) from the discharge point.

Filtration. Seven 20 in by 20 in (0.508 by 0.508 m) aluminum baffle filters.

Cooking Equipment and Dimensions of its Heated Surface.

1. Gas fryer—98,000 Btu/h (28.7 kW)—211/2 in by 14 in (0.546 m by 0.356 m)
2. Gas fryer—105,000 Btu/h (30.7 kW)—211/2 in by 14 in (0.546 m by 0.356 m)
3. Chain broiler and flat grill—71,000 Btu/h (20.8 kW)—32 in by 21 in (0.813 m by 0.533 m)

Building Pressure. Front door—0.015 in water (3.74 Pa) negative; back door—0.025 in water (6.23 Pa) negative.

Pertinent Information.

1. Height from cooking surface to lower edge of the hood was 42 in (1.067 m).
2. Hood hanging height was 78 in (1.981 m) A.F.F.
3. Hood overhang was more than sufficient. There was at least 9 in (0.229 m) of overhang on every piece of equipment.
4. Two 2 ft by 2 ft (0.610 m by 0.610 m) perforated plate ceiling diffusers were positioned along the length of the hood approximately 30 in (0.762 m) from the hood's front edge. These diffusers discharged outside air in this region at a face velocity of approximately 200 fpm (1.016 m/s) to help relieve any negative pressure created by the hood.

DISCUSSION—EXPERIMENT ONE

In experiment one the first objective was to determine the minimum obtainable exhaust that would still contain all the smoke created by the smoke bomb without supplying any make-up air to the hood. Due to the air-conditioning diffuser mentioned previously, the hood would not capture the smoke at the left end of the hood. With the exhaust at 9800 cfm (4626 L/s) and the make-up air turned off, the smoke still drifted to the left end of the hood, where it was entrained into the diffuser's draft and blown onto the floor and out into the kitchen. Disregarding the performance of the hood in this area, the exhaust fan was adjusted to its lowest setting. At 5861 cfm (2681 L/s) exhaust, the hood captured the smoke in every region except on the left end. It is my opinion that a lower exhaust setting would have been adequate had the drafts created by the air-conditioning diffuser not been present. Following is a comparison of this exhaust level with that specified by other design methods:

NFPA 96	14,400 cfm (679 L/s)
Manufacturer's Data (Light Load) (UL Classification)	6160 cfm (2908 L/s)
Greenheck Design Method	4806 cfm (2269 L/s)
Actual Test Exhaust	5681 cfm (2681 L/s)

The next goal was to determine how much make-up air could be introduced with the exhaust level at 5681 cfm (2681 L/s) while maintaining capture. Disregarding the performance of the left side of the hood, the highest level of supply air that could be provided while still maintaining capture was 2421 cfm (1143 L/s). At this supply level the following observations were made:

1. The average MUA discharge velocity was 221 fpm (1.123 m/s). This velocity varied from 330 to 120 fpm (1.676 to 0.610 m/s).
2. When the MUA discharge velocity was above 220 fpm (1.016 m/s), the supply air would impinge upon the cooking surface, causing some turbulence in the smoke rising off the front portion of the cooking equipment.
3. More recapture of the smoke in the hood was noticed after turning on the supply air. The air curtain seemed to draw the rising smoke away from the filter rack, causing more smoke to pass the filters and roll around in the hood before being exhausted.
4. The MUA improved the hood's capture on its left end, but did not eliminate the escape of smoke into the room. The hood's air curtain in this region blocked smoke from escaping at the lower edge of the hood, but as the smoke was entrained into the downward flow, it would begin to drift out from under the hood.
5. A smoke bomb released in the MUA fan indicated approximately 60% of the supply air was drawn into the hood and 40% spread out into the kitchen. It was hard to gauge the effect of the MUA on the kitchen environment since an undetermined amount of MUA was mixing with the room's conditioned air.

The hood manufacturer specifies that 6160 cfm (2908 L/s) exhaust and 5420 cfm (2558 L/s) supply should be used for this application. The actual net loss of air from the kitchen was much greater than that specified by the manufacturer; however, the primary cause of the hood's lack of performance was an air-conditioning diffuser's location. The test seems to indicate that while the hood probably could not operate at the manufacturer's specifications, the fans suggested by these specifications could be adjusted to the proper level to make the hood capture. The test also shows the exhaust requirements of NFPA 96 are much greater than necessary when the hood is not subjected to strong room drafts. The most important conclusion to be drawn from the test is that the HVAC design is critical to the hood's performance. When improperly designed, the HVAC system can prevent the hood from working, regardless of the amount of exhaust or supply being used.

Several modifications could be made to this hood that would improve its performance. Use of grease filters with a higher static pressure would spread the exhaust more evenly throughout the hood and improve the capture at the ends of the hood. The grease filter face velocity varied between 140 and 480 fpm (0.711 and 2.438 m/s) with the mesh filters. In my opinion, directing the MUA into the hood by use of a grille with angled vanes would improve the hood's capture. The MUA slot on this hood discharged MUA straight down, causing some smoke and supply air to be blown onto the floor, where they dissipated into the room. By directing the MUA into the hood, this would not occur; however, the level of MUA used would have to be lowered to maintain capture.

DISCUSSION—EXPERIMENT TWO

In experiment two, the first objective was to determine the minimum obtainable exhaust that would still contain all the smoke created by the smoke bomb inside the hood with the MUA fan turned off. The exhaust fans were set at their lowest setting. The exhaust was measured at 2718 cfm (1283 L/s). At this level of exhaust with the MUA fan turned off, a 185 fpm (0.940 m/s) discharge velocity could be measured in the MUA slot. This draft was created by the negative pressure in the building caused by the MUA fan being off. Approximately 440 cfm (208 L/s) was being drawn through the MUA slot; therefore, the net air loss from the kitchen was approximately 2278 cfm (1075 L/s). The hood smoke tested beautifully at this setting.

The MUA fan was then turned on and the supply air volume dampers were adjusted to find out how much MUA could be added to the hood while maintaining its capture ability. After many tests, the average supply slot velocity was finally set at 608 fpm (0.305 m/s). This provided 1447 cfm (683 L/s) internally to the hood's capture area, which created a net air loss from the kitchen of 1271 cfm (600 L/s). The hood still captured all the smoke created by the smoke bomb at these settings. These results were quite amazing. After rechecking the figures and readings and cross-referencing fan curves, the performance of this hood was confirmed. There was no turbulence in the hood, despite the high discharge velocity of the MUA slot. This can be attributed to the perfect alignment of the MUA slot relative to the filters.

There were several factors contributing to the highly efficient performance of this hood. The hood had two exhaust risers. This created very little variation in the exhaust filter face velocity. The filter face velocities ranged from 170 to 260 fpm (0.864 to 1.321 m/s); the average velocity through each filter ranged from 204 to 232 fpm (1.036 to 1.179 m/s). The MUA slot velocity was also relatively even. The MUA slot velocity varied from 440 to 730 fpm (2.235 to 3.708 m/s). Fortunately, the highest MUA slot velocities were located in regions with higher exhaust velocities. The most significant factor contributing to the hood's performance was the kitchen's perfect environment. There were virtually no drafts in the region of the hood, and the two ceiling diffusers—mentioned previously—eliminated the negative pressure created by the hood along the cooking line. The excessive overhang and lack of cooking equipment under this hood also helped its performance. (The chain broiler was 6 ft by 2 ft [1.829 m by 0.610 m] in overall size, but only had a 32 in by 21 in [0.813 m by 0.539 m] cooking surface.)

A comparison of the minimum net exhaust level arrived at through testing with that specified by other design methods reveals the following:

NFPA 96	4085 cfm (1928 L/s)
Manufacturer's Data (UL Classification)	2929 cfm (1382 L/s)
Greenheck Design Method	2158 cfm (1019 L/s)
Actual Test Exhaust	2718 cfm (1283 L/s)
Net Exhaust During Test	1271 cfm (600 L/s)

The test indicates that the manufacturer's data are closest to the actual needs of the system. The manufacturer specifies up to 70% of the exhaust can be made up through internally discharged MUA when the hood is set at its UL-classified exhaust level of 251 cfm (118.5 L/s) per linear foot of hood. The test shows that in an ideal situation, the hood achieved a 53% MUA to exhaust ratio over a medium cooking load with an exhaust level of 233 cfm (110 L/s) per linear foot of hood. I do not believe the results could improve to the manufacturer's claims; however, the specifications provided by the UL classification of this hood seem to be the closest approximation to the hood's actual performance.

CONCLUSIONS

The results of the tests indicate there are differences between hood designs. These differences can be measured in terms of the design's efficiency, effect on the kitchen environment, and cost of operation. When choosing a hood design, all these factors must be considered.

The tests indicate that a properly designed compensating hood can reduce the net exhaust required to capture the contaminants produced by a line of cooking equipment. The efficiency of the compensating hood is largely controlled by the direction and velocity of its MUA slot. If the MUA discharges in a manner that creates turbulence or fights the natural rise of heated air from the cooking surface, the compensating hood will not function efficiently. The MUA should act to contain contaminants inside the capture area and/or direct them toward exhaust filters without causing turbulence. Similar types of hoods can perform very differently due to variations in slot, grille, and filter dimensions and locations. The objective of this report is to identify the limitations and advantages of the basic designs currently in use and the types of designs to avoid.

Another conclusion drawn from the test results is that a hood's UL classification and/or listing is a reasonably close estimate of the actual exhaust and supply requirements of the hood. While the supply requirements specified are usually higher than achievable, the exhaust and supply fans provided to obtain the UL-specified values can usually be adjusted so the hood operates properly. The UL classification and/or listing will also satisfy most code requirements; therefore, this appears to be the most accurate and acceptable way to estimate exhaust and supply air requirements for kitchen ventilation hoods.

Several installations were tested that did not provide any type of useful information. These installations had operational problems that would not allow the tests to be performed in the manner desired. Some of the problems I encountered are listed below:

1. An air-curtain-type hood was found with a gravity feed MUA duct. The MUA plenum was coated with grease, which collects there when contaminated heated air travels up into this plenum during operation of the cooking equipment.
2. Air-conditioning return grilles within 4 ft (1.22 m) of the hood. These grilles prevented the hood from capturing at any level of exhaust.
3. Rusted pulleys that could not be adjusted. The pulleys could not be changed because they were rusted to the shaft of the motor.
4. No MUA dampers in the ductwork or hood, causing uneven distribution of the MUA throughout the hood.
5. Burned-out fan motors.
6. MUA plenum perforated plate diffuser panels were

found blocked with debris not filtered out by the MUA fan.

7. Broken belts on exhaust and supply fans.
8. Hoods with equipment protruding from underneath them.
9. Hoods with missing or damaged filters.

These installations indicate that any kitchen ventilation system is useless if not properly applied and maintained.

Every hood must be balanced to perform properly. The hood must also be maintained to keep its balance. The filter and duct system must be regularly cleaned, and the fans must be periodically checked and serviced. Peak performance and efficiency can only be achieved by proper adjustment and maintenance of the ventilation hood.

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