Supplemental Research to ASHRAE 1202-RP

Effects of Range Top Diversity, Range Accessories, and Hood Dimensions on Commercial Kitchen Hood Performance

Final Report – January 2006

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Acknowledgments

The authors acknowledge the many people who helped with the planning and completion of this research project. The enthusiasm of our industry colleagues toward this commercial kitchen ventilation (CKV) study was remarkable, while manufacturers' contribution of appliances and hoods for testing was vital to its outcome. We found ongoing support from the kitchen ventilation industry as we updated interested parties at professional meetings and forums, participated in ASHRAE seminars, provided tours of the CKV laboratory and demonstrations of our findings.

We extend our appreciation to Greenheck Fan Corporation, Vulcan-Hart Corporation, the Frymaster and Garland divisions of Enodis, Southbend, Magikitch'n, and the Montague Company, for providing test equipment. A thank you is also owed to Tim Cole of the Gas Technology Institute, who handed down valuable instrumentation when he decommissioned a recognized CKV research facility in Cleveland, Ohio.

It is essential to acknowledge the Electric Power Research Institute (EPRI) as one of the original proponents for CKV research. This project would not have been viable without the significant investment that EPRI made in the CKV test facility and protocols from 1993 to 1999, especially in the focusing schlieren flow visualization system. The California Energy Commission (CEC) Public Interest Energy Research (PIER) project, Makeup Air Effects on Kitchen Exhaust Hood Performance, laid the foundation for research in CKV makeup air design and installation. The results showed how subtle changes could dramatically affect hood performance, and revealed the need to investigate appliance diversity and positioning. To further the CKV research, the invaluable support of the CEC has continued in collaboration with the Gas Technology Institute for this ASHRAE project. With respect to the suggestions and contributions of individuals, please know your efforts are greatly appreciated.

Finally, we would like to recognize the continuing support of the Pacific Gas and Electric Company. The establishment of the Food Service Technology Center (FSTC) reflects Pacific Gas and Electric Company's commitment to the food service industry. A goal of the FSTC research program is to provide California utility customers and the food service industry with information to help them improve the performance and energy efficiency of CKV systems.

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Preface

Over the past ten years, the ASHRAE Technical Committee, TC 5.10 on Kitchen Ventilation, has conceived and administered research projects that have significantly advanced the state-of-knowledge with respect to the design and application of commercial kitchen ventilation systems. One such project that was recently completed was ASHRAE Research Project 1202 Effect of Appliance Diversity and Position on Commercial Kitchen Hood Performance.

The objective of the research project was to quantify the impact that appliance position and/or the mix of appliances under an exhaust hood had on the minimum exhaust airflow required for capture and containment. Appliances typically found in a commercial kitchen (providing cooking operations for broiled meats, fried products, and baked goods) were used for the testing.

While the project was being developed, it became apparent that the information being learned could be greatly augmented by testing subtle configuration changes, as well as adding in configurations that were of interest but were beyond the scope of the ASHRAE project's goals. Therefore, a supplemental project, funded by the Pacific Gas and Electric and Company and the Gas Technology Institute, was developed with the approval of ASHRAE to study how hood dimensions, hood filter location, hood mounting height, appliance accessories, and variations of range top usage affected hood performance.

The combined projects provided information that can be used to refine the current guidelines for kitchen ventilation design and provided insight for specifying energy efficient cook lines and hoods. The key was studying the hood and appliances as a system and realizing that subtle changes can have a dramatic affect on system performance. The best location for appliances in the cook line, combined with the best overhang dimensions for each appliance, was complimented with the optimal hood height and depth dimensions for that particular cook line. Furthermore, the impact of the accessories and appliance usage allow fine-tuning of the layout, operation, and ventilation of the cook line.

Executive Summary

A number of studies have examined the capture and containment (C&C) exhaust rate requirements for single appliances operating under wall canopy hoods. However, very limited data existed for multiple appliances. Combining this supplemental research project, which was co-funded by the Pacific Gas and Electric and Company and the Gas Technology Institute, with the primary ASHRAE Research Project 1202 Effect of Appliance Diversity and Position on Commercial Kitchen Hood Performance [Ref 1], provided a unique opportunity to further the public knowledge of energy conservation strategies for the commercial kitchen. A significant reduction in energy consumption for ventilating and tempering the kitchen environment can be realized by educating the commercial kitchen community so they can skillfully apply subtle installation specifications for the hood and appliance line, such as appliance placement and usage.

The objective of this supplemental study was to quantify the effects that range top diversity, range accessories (including shelving and a salamander), and hood dimensions (including hood height, depth and reservoir volume) have on hood performance with respect to the minimum exhaust rate required for complete capture and containment of cooking effluent. The appliances included a 6-burner gas range, a gas salamander, three underfired gas broilers, three 2-vat gas fryers, and three electric full-size convection ovens.

Key Findings

Many of the general observations found during this supplemental research can be applied as best practices for designers, installers, and operators. These observations include:

- Positioning an appliance so that its thermal plume is inside the hood’s perimeter as far as possible will improve C&C performance.
- Positioning heavy-duty appliances towards the center of a cooking equipment line will enhance capture and containment.
- Installing shelving or ancillary equipment such as a salamander behind or above an appliance typically will not have a detrimental impact on C&C performance, provided other best practices (e.g., maximizing hood overhang) are observed.
- Maximizing front overhang while minimizing rear clearance can greatly improve C&C performance.
- Specifying partial side panels will improve hood performance.
- Increasing hood depth (front-to-back) will improve C&C performance when this additional hood depth is used to maximize the front overhang dimension.
- A taller hood with increased reservoir capacity may improve C&C performance by allowing a concentrated plume to be more evenly distributed along the filter bank.
- Installing hoods at the lowest height practical (or permitted by code) to minimize the distance from the cooking surface to the hood will improve C&C performance.

Effect of 6-Burner Range Top Diversity and Accessories on Capture and Containment Performance

With the 6-burner range top positioned in the left end position under the hood, the required C&C exhaust rate varied significantly (from 250 cfm/ft to 470 cfm/ft) as a function of the location and number of burners being used. This variation implies that the design exhaust rate for a gas range top will be dependent on its usage in different food service operations. There will be applications where the range top is solidly in the heavy-duty category, while other times a medium-duty classification may be adequate.

Contrary to researchers' expectations, in all but one configuration tested, neither solid nor tubular shelving over the 6-burner range required an increase in the exhaust rate. In fact, tubular shelving mounted to the back of the appliance showed a slight enhancement when compared to having no shelving installed.

Also contrary to expectations, a gas-fired salamander positioned over the 6-burner range did not exhibit a negative effect on hood C&C performance. In all but one case, it was best to mount the salamander on the back wall rather than on the appliance. For 6-burner and 3-front-burner operation, the exhaust rate actually decreased when the salamander was installed.

Effect of Hood Depth on Capture and Containment Performance

Comparing the 4-foot and 5-foot deep hoods found a trend that was consistent for all tested cook lines - the exhaust rates required for C&C were more dependent on the clearance between the back of the appliances and the wall than the front overhang dimension. In some cases tested when the rear gap between the appliance and the wall was equal, there was no significant advantage in using the 5-foot deep hood over the 4-foot deep hood. When the front overhang was set to a minimum 6.0 inches, the 5-foot hood required significantly more exhaust than its 4-foot counterpart, due to the corresponding increase in gap between the appliance and the back wall.

The greatest advantage of the 5-foot over the 4-foot hood was its ability to capture and contain the plume when an oven door was opened, provided the 5-foot depth was used to maximize the front overhang. It also showed an advantage over the 4-foot hood in C&C performance over the heavy-duty gas broiler line, when the rear gap was minimized and the front overhang was maximized.

Effect of Hood Reservoir Volume on Capture and Containment Performance

Increasing the reservoir volume by adding a 1-foot skirt to the lower edge of the hood and maintaining a constant distance from the broiler to the lower edge of the hood provided an effective way to evaluate the effect of increased hood reservoir volume. When the broiler was operated in the left appliance position, the increased hood volume demonstrated a marginal improvement in C&C performance. The 200 cfm or 5% improvement for the left appliance location indicated the key to C&C was not the hood volume, but rather the air velocity to turn the plume into the hood. In contrast, the 1100 cfm or 35% improvement found for the center appliance position was significant. This improvement indicated the plume was well located in the hood and the increased hood volume would allow the plume to roll inside the hood and distribute itself more evenly along the length of the hood's filter bank.

Decreasing the reservoir volume of the 5-foot deep hood to the approximate volume of the 4-foot deep hood did not affect the C&C performance when challenged by the three-broiler line. In this case, the greater hood depth affected the C&C requirement more than the reservoir volume with the lowered hood ceiling.

Effect of Hood Mounting Height on Capture and Containment Performance

Minimizing the hood mounting height had a positive effect on C&C performance. In most cases, a direct correlation could be made between the required exhaust rate and hood height for a given appliance line. Of interest to CKV system designers is the tradeoff when the 6.5-foot minimum mounting height for a canopy hood is increased to 7.0 or 7.5 feet. For the gas broiler installed at the end of the cook line, increasing the hood height by 1 foot required a 14% increase in exhaust rate. However, when the broiler was placed in the center position, the increased hood height did not compromise C&C performance or require a higher exhaust flow rate. As the hood-to-appliance distance was reduced below the standard 6.5-foot mounting height, dramatic reductions of the exhaust requirement were found. This exhaust reduction illustrates the potential for optimizing CKV systems through the application of close-coupled proximity hoods.

Effect of Hood Filter Height and Location on Capture and Containment Performance

Evaluation of the location and size of the hood filters was performed with one heavy-duty range operating at the end appliance position. The question was whether the taller filters with more open area or the shorter filters with the higher relative face velocity would have an advantage. The effect of locating the short filters either high or low in the hood was also evaluated. While this single data point cannot be used as a general statement, some observations were made.

- When located higher in the hood, shorter baffle filters showed a significant C&C exhaust rate reduction, compared to taller filters. In this configuration, the C&C exhaust rate was reduced from 4700 to 4050 cfm (470 to 405 cfm/ft), or 14%, with a 6-burner range operating at full input.
- When located low in the hood, shorter baffle filters reduced the C&C exhaust rate from 4700 to 4600 cfm (470 to 460 cfm/ft), or 2%.
- Overall, the shorter filters with the reduced filter face area and higher relative face velocities demonstrated improved C&C performance.

Focus of Further Research

Subtle differences in the hood/appliance configuration were shown to have a significant affect on C&C performance. Further investigation into these subtleties could provide a greater understanding of how to optimize the hood and appliance system. For instance, different side panel profiles could be evaluated to see if the horizontal or vertical dimension has the greatest affect on hood performance. The flanges along the lower edge of the hood could be evaluated to determine if there is an optimal configuration, if the optimal configuration is different for the front edge and side edges, if the side flanges need to be removed when side panels are installed, and if the appliance line affects the side panel configuration. Pushing back appliances in the cook line could be further studied to quantify the impact as a general rule of thumb and to study subtleties of specific appliances and hood geometries. Shelving installations over various appliance duties and configurations would help to characterize the affect of shelving on hood performance.

In addition to evaluating the hood and appliance systems, refinement to the capture and containment test method may be worthwhile. Currently, the capture and containment airflow rate is determined at the lowest airflow rate where no spillage of effluent is observed. However, the idea of quantifying the amount of spillage has been considered as a method of evaluating less than “perfect” hood performance. The challenge is quantifying the volume of spill at any given time. The ability to quantify the performance of a well or poorly designed kitchen ventilation system or intermittent field conditions and may help address both the required degree of performance of the hood and the actual performance found in the field.

Applying the Findings

Future efforts will include an update to the design guide series, which was started as a part of the team’s makeup air research. This update will further complete the “picture” of how to optimize an appliance/hood system. A symposium presented both the main [Ref 2] and supplemental [Ref 3] study during the 2006 ASHRAE winter meeting, and the technical papers are available to the public. Furthermore, these supplemental and research reports are publicly available through the Pacific Gas and Electric Company’s Food Service Technology Center at www.fishnick.com.

In an effort to provide this information to the public as quickly as possible, an article titled “Push ‘em back, push ‘em back… and boost the performance of your kitchen exhaust hood” has already been published by Richard Young in The Green Sheet section of the August 2005 California Restaurant Bulletin [Ref 4]. This article clearly states how simply moving appliances can benefit kitchen ventilation performance and offers a link to www.fishnick.com, where an online tutorial including flow visualization movies can be found.

Abstract

This report summarizes a laboratory investigation into the effects that range top diversity, range accessories (including shelving and a salamander), and hood dimensions (including hood height, depth and reservoir volume) have on hood performance with respect to the minimum exhaust rate required for complete capture and containment of cooking effluent. The appliances used for the study included a 6-burner gas range, a gas salamander, three underfired gas broilers, three 2-vat gas fryers, and three electric full-size convection ovens. The appliances were operated under a 10-foot long wall-mounted canopy hood and were evaluated in accordance with ASTM 1704-99 Standard Test Method for Performance of Commercial Kitchen Ventilation Systems. This study was a co-funded supplement to *ASHRAE 1202 RP Effect of Appliance Diversity and Position on Commercial Kitchen Hood Performance*.

Introduction and Background

An effective commercial kitchen exhaust hood must ensure complete capture and containment (C&C) of the effluent produced by the cooking processes so it can be removed from the space. This effluent includes smoke, grease particles and vapor, products of combustion, heat, and moisture. The energy burden for this ventilation process has driven strategies to optimize the appliance and hood configurations in an effort to reduce the energy required for the fans and for tempering the replacement (makeup) air.

A number of studies have examined the C&C exhaust rate requirements for single appliances operating under wall canopy hoods. The gas and electric utility industries have sponsored the majority of this work in the pursuit of improving appliance and ventilation efficiency. This work has been incoporated within the ASHRAE Handbook Chapter on Kitchen Ventilation [Ref 5]. ASHRAE Research Project 1202 built on data found in the ASHRAE Handbook, compiling information for multiple appliance operations and examined how appliance position and diversity influenced the C&C exhaust rate and the heat gain to space. The findings of the primary study are presented in *1202 RP Effect of Appliance Diversity and Position on Commercial Kitchen Hood Performance* [Ref 2]. The findings of the supplemental study are presented in *1202 RP Effect of Range Top Diversity, Range Accessories, and Hood Dimensions on Commercial Kitchen Hood Performance* [Ref 3]. This report presents the results from the supplemental study to 1202 RP, which was co-funded by the Pacific Gas and Electric Company and the Gas Technology Institute.

Objective and Scope

The objective of this supplemental study was to quantify the minimum exhaust rate required for complete capture and containment using different appliance, accessory, and hood configurations as well as different cooking operations.

A 6-burner range operated with either the front, rear, left, right, or all six burners in operation. The impact of typical accessories mounted above an appliance was also evaluated with the 6-burner range. The accessories evaluated were solid and tubular shelving, and a gas-fired salamander. These accessories were tested as wall-mounted and appliance-mounted units.

Appliance positioning relative to hood front overhang was evaluated with heavy, medium, light, and multi-duty appliance lines. Each cook line was moved from the minimum to the maximum possible front overhang dimension for that particular cook line and hood configuration. Another test was performed with the multi-duty cook line to compare a cook line that was lined up at the front of the appliances to a cook line that was staggered at the front of the appliances to maximize the front overhang for each appliance on the cook line.

The impact of hood design on exhaust requirements was evaluated using consistent cook lines. Hood mounting height was evaluated by changing the vertical distance from the appliance to the lower edge of the hood. Hood geometry was evaluated by physically cutting the hood to change the hood height and depth, as well as by installing side panels and evaluating variations of filter height and location.

Experimental Design

Laboratory Overview

The CKV laboratory located near Chicago was constructed to dimensions of a typical commercial kitchen. The structure consists of layered airtight walls and multiple airtight roof penetrations or “curbs” to which hoods and fans could be installed in various locations throughout the facility. The laboratory doors are custom fabricated and sealed to provide access to the room without allowing air leakage. Within this laboratory environment, the commercial kitchen appliances and hoods are evaluated using sophisticated schlieren and shadowgraph flow visualization technology. A plan view of the laboratory set-up is shown in Figure 1. A detailed description of the laboratory is found in Appendix A.

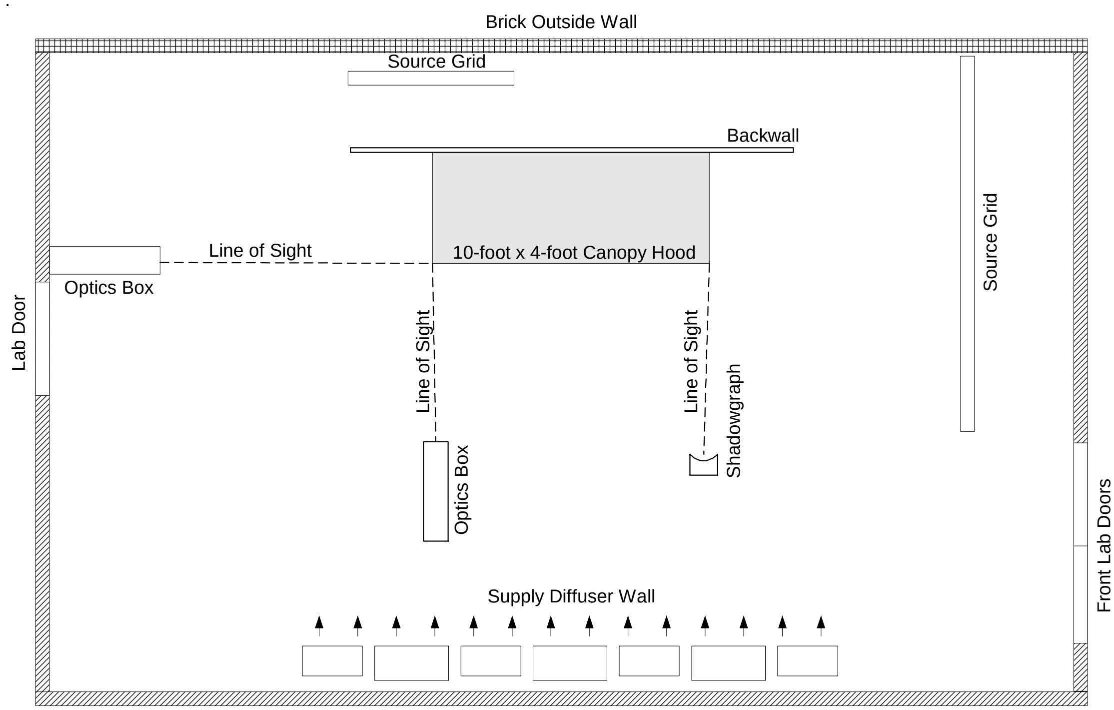

Figure 1. Plan View of Laboratory Set-up

Makeup Air Specifications

The replacement air for the laboratory was supplied by a 20-foot wide by 5-foot high displacement ventilation system, located 12 feet in front of the hood. This makeup air design provided low-velocity air, which minimized the impact of makeup air on the test results and ensured repeatable best-case scenarios. The benefits of an optimized makeup air configuration were proven during a study sponsored by the California Energy Commission and a summary was published as part of the design guide series [Ref 6]. The laboratory supply diffusers are shown in Figure 2.

Figure 2 Floor Mounted Displacement Ventilators as Used for Laboratory Air Supply

Hood and Side Panel Specifications

The canopy hood measured 10-feet wide by 4-feet deep by 2-feet high and was mounted to a transparent back wall. It was equipped with baffle-type grease filters, and exhausted through a 36.0 inch by 12.0 inch exhaust collar. The front lower edge of the hood was usually located at 78.0 inches above the finished floor. A 6.0 inch fascia was attached between the top of the hood and the suspended ceiling. The suspended ceiling was located 108.0 inches above the floor. The hood was equipped with open hems on three sides of the hood for mounting side panels and hood extensions. To allow for generic testing, the canopy hood did not have performance enhancing features, such as flanges or lips. A drawing of the hood is shown in Figure 3 and a photograph is shown in Figure 4.

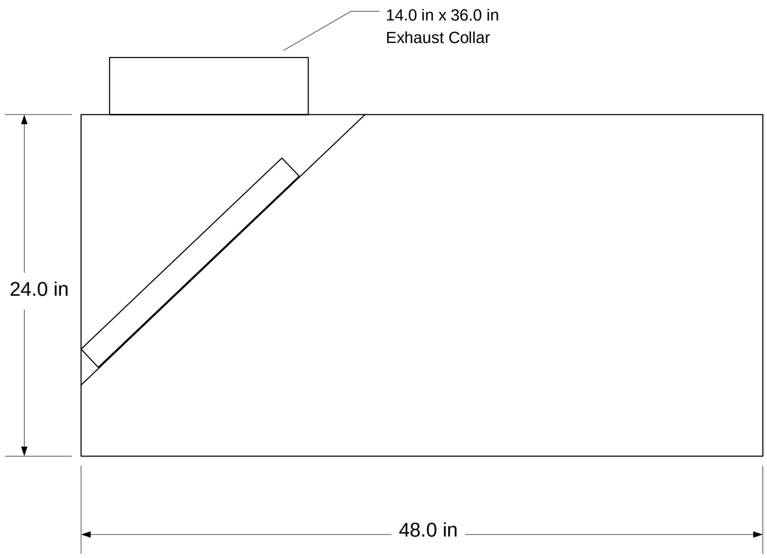

Figure 3. Cross Section Drawing of the Exhaust Only Canopy Hood

Figure 4. Right Isometric Photograph of the Exhaust Only Canopy Hood Mounted to a Transparent Wall

For evaluation of hood performance based on hood depth, the hood was modified to a depth of 5 feet with all other features remaining the same. This was accomplished by cutting the front surface of the hood off, installing 1 foot spacers on the front edges of the left, top, and right of the hood, and then reattaching the front surface of the hood to the spacers. This set-up is illustrated in Figures 5 and 6.

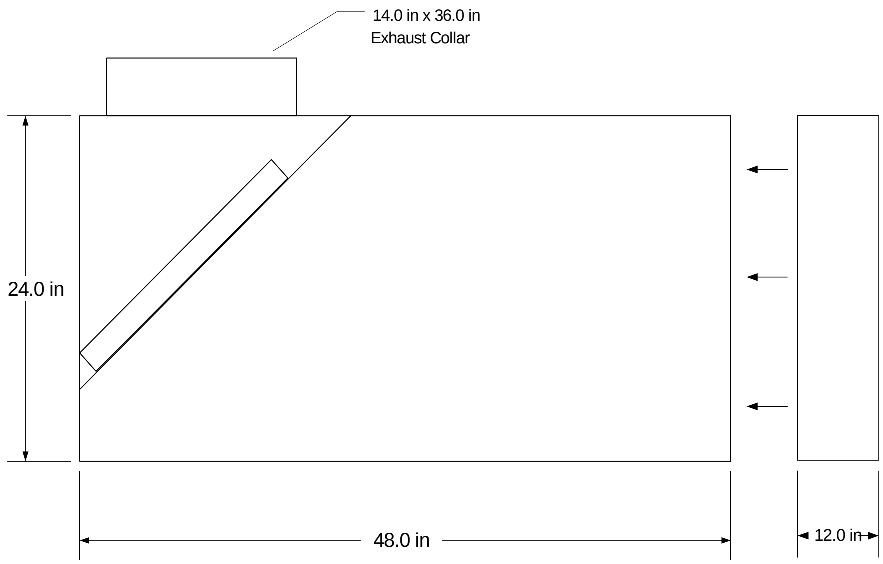

Figure 5. Cross Section Drawing of 1 foot Hood Depth Modification

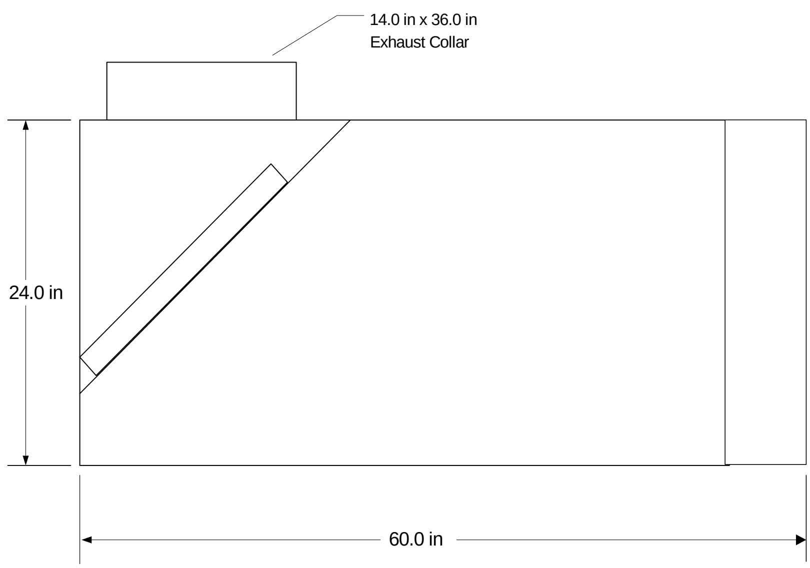

Figure 6. Cross Section Drawing of Hood with 1 foot Hood Depth Modification Installed

For evaluation of hood performance based on how tall the hood was, a 1-foot skirt was added to the bottom edge of the hood. To compensate for the hood being one foot closer to the appliances during this evaluation, the appliance used for the evaluation was lowered one foot to maintain a consistent distance from the appliance to the lower edge of the hood. This hood set-up is illustrated in Figures 7 and 8.

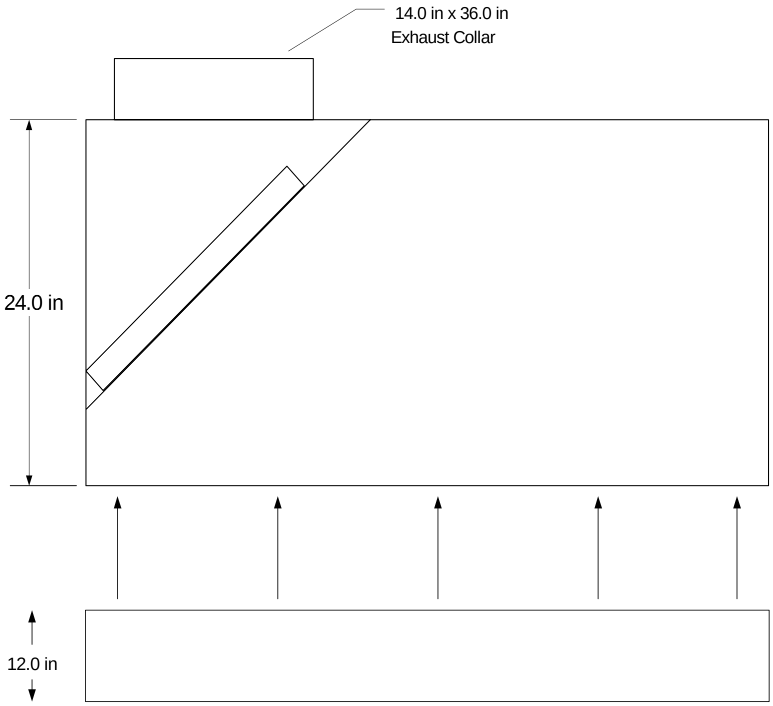

Figure 7. Cross Section Drawing of 1-Foot Hood Skirt Modification

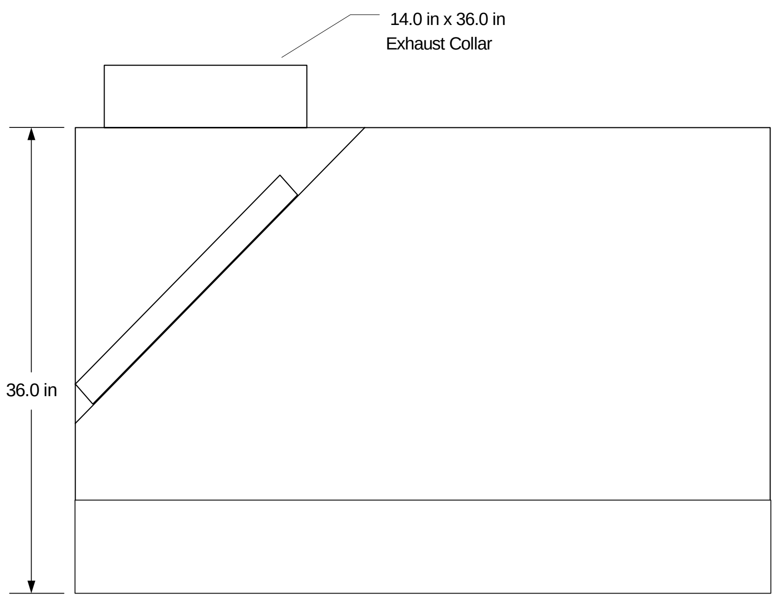

Figure 8 Cross Section Drawing of Hood with 1-Foot Hood Skirt Installed

To compare hood performance with a similar reservoir volume but with an increased hood depth, a false ceiling was installed approximately 6 inches below the actual ceiling in the 5-foot deep hood. This installation provided the approximate reservoir volume of the 4-foot deep hood while providing the increased overhang of the 5-foot deep hood. The set-up is illustrated in Figure 9.

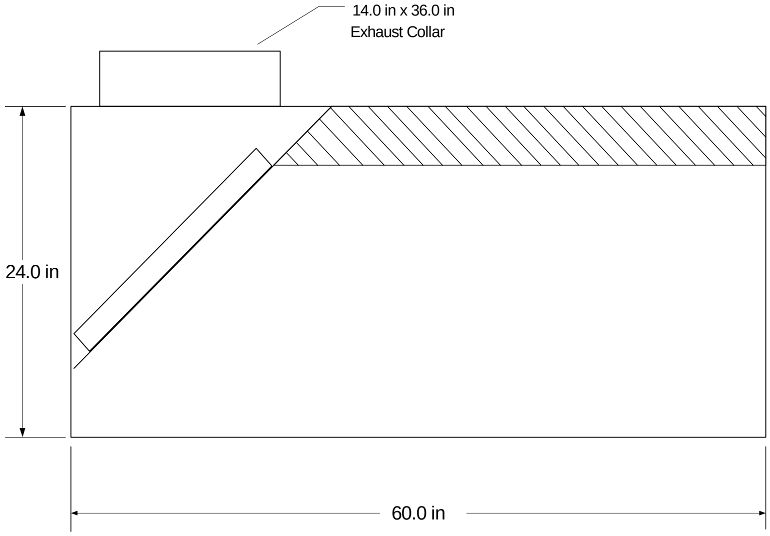

Figure 9. Cross Section Drawing of Hood with Increased Depth and Reduced Reservoir

For most of the supplemental evaluations, side panels were not used. However, for some investigations, a 4-foot by 4-foot partial side panel was used. This side panel had equal vertical and horizontal dimensions, and tapered from the front upper corner to the lower rear corner, which resulted in an edge that was at a 45° angle. A photograph of the side panels installed on a broiler cook line is shown in Figure 10 and a line drawing is shown in Figure 11.

Figure 10. 4x4x45° Partial Side Panels Installed on Canopy Hood

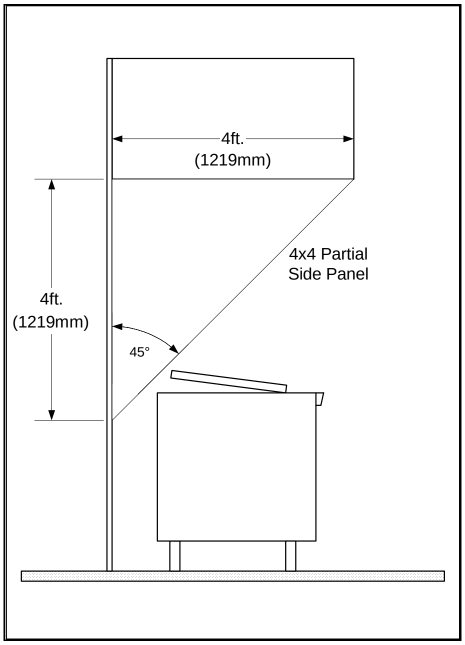

Figure 11. Line Drawing of 4x4x45° Partial Side Panels Installed on Canopy Hood

Appliance Specifications and Calibrations

The appliances included a 6-burner gas range, a gas salamander, three gas broilers, three 2-vat gas fryers, and three full-size electric convection ovens. The appliances were calibrated according to ASTM Standard Test Methods [Ref 7], [Ref 8], [Ref 9], and [Ref 10]. The 2-vat fryers and broilers then operated at ASTM full-load cooking conditions and the full-size convection ovens used an ice load to cause continuous burner operation. Simulation of the ASTM specified cooking conditions was achieved for the fryers by using a calibrated water boil to generate a thermal plume that matched the plume from cooking shoestring potatoes. Simulated cooking for the broilers was achieved by increasing gas pressure to the burners, which produced a thermal plume of volume and strength that matched the plume from cooking hamburger patties. The full-size electric ovens required the same exhaust rate for either idle or cooking conditions. These realistic substitutes for actual cooking greatly accelerated testing by creating a constant effluent challenge, improving repeatability, and reducing laboratory time and product cost. The appliance specifications shown in Table 1 below and the appliances are shown in Figures 12 through 16.

Table 1 Appliance Specifications

	3-Foot Gas Broiler	Full-Size Electric Convection Oven	Two Gas Fryers	6-Burner Gas Range	Gas Salamander
Capacity	58.4 sq. in.	8.6 cu. ft	Two 50 lb. vats	Six 20,000 Btu/h burners	381.4 sq. in.
Rated Input	96,000 Btu/h	12.1 kW	160,000 Btu/h	120,000 Btu/h	30,000 Btu/h
Height	37.0 in.	57.3 in.	45.3 in.	44.5 in.	14.0 in.
Width	34.0 in.	40.0 in.	31.3 in.	36.3 in.	34.0 in.
Depth	33.0 in.	40.5 in.	28.5 in.	32.5 in.	18.0 in.

Figure 12. Heavy-Duty 6-Burner Range

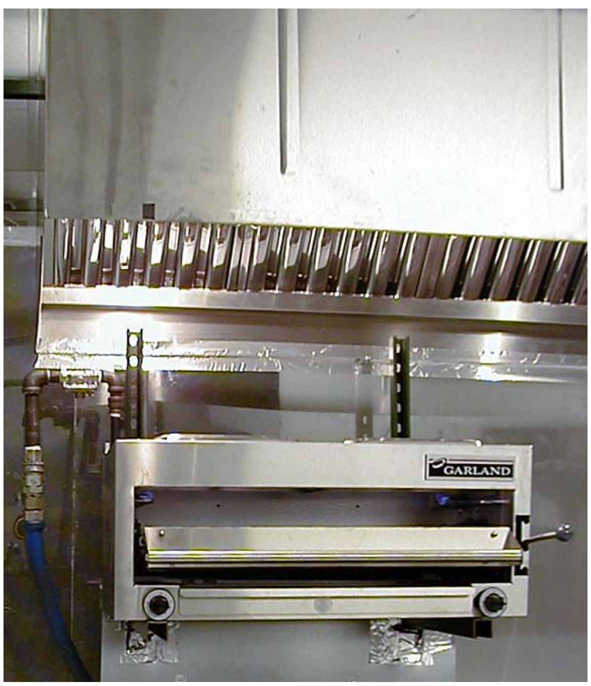

Figure 13. Heavy-Duty Salamander

Figure 14. Three Heavy-Duty Broilers

Figure 15. Three Medium-Duty 2 Vat Fryers

Figure 16. Three Light-Duty Full-Size Ovens

Hood/Appliance Relationships

For most tests, hood overhang was set to 6.0 inches as measured horizontally from the front, left, and right edges of the 10-foot hood to the appliance. However, since the width of three ovens slightly exceeded the width of the hood, the cavity side of the left oven was set in line with the left side of the hood (i.e., 0 inches of side overhang) and the controller side of the right oven extended beyond the right hand side of the hood by 0.8 inches. The front overhang was reported from the front of the hood to the front of the appliance. Alternatively, building codes or code enforcement officials may measure the hood front overhang to the front of the cooking surface. Table 2 presents the relationship between the front edge of the hood and the front edge of the appliance or cooking surface, and the rear of the appliance to the wall for the appliances tested. Figures 17 and 18 illustrate the direct relationship of front overhang and rear clearance.

Table 2. Relationship of Hood, Appliance Cabinet, Appliance Cook Surface, and Wall

	Oven	Fryer	Broiler	Range
Hood Front Overhang to Appliance [in.]	6.0	6.0	6.0	6.0
Hood Front Overhang to Cooking Surface [in.]	6.0	9.0	12.0	6.0
Rear of appliance to Wall for 4-Foot Hood [in.]	1.5	13.5	9.0	9.5
Rear of appliance to Wall for 5-Foot Hood [in.]	13.5	25.5	21.0	21.5

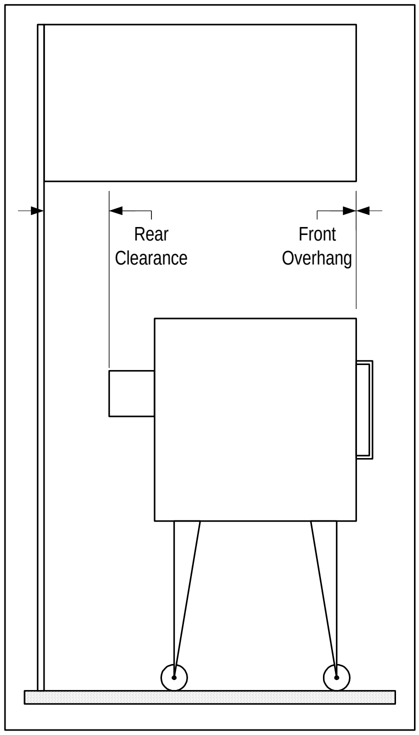

Figure 17. Minimum Front Overhang Compared to Rear Clearance for Ovens under the Wall-Mounted Canopy Hood

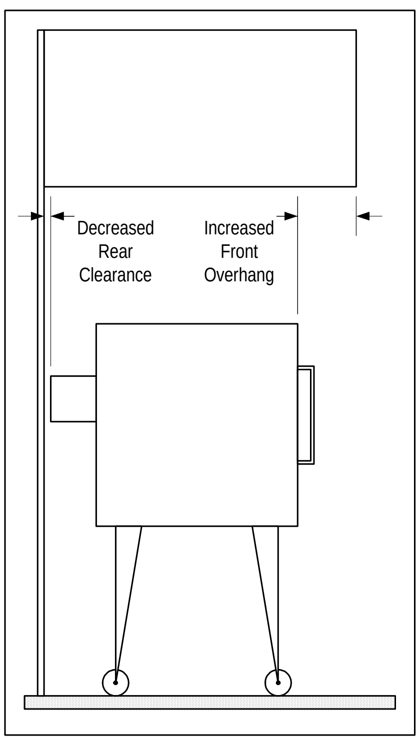

Figure 18. Maximum Front Overhang Compared to Rear Clearance for Ovens under the Wall-Mounted Canopy Hood

1. Method

Capture & Containment Testing

"Hood capture and containment" is defined in ASTM 1704 *Standard Test Method for the Performance of Commercial Kitchen Ventilation System*s as "the ability of the hood to capture and contain grease laden cooking vapors, convective heat and other products of cooking processes". Hood capture refers to the products getting into the hood reservoir, while containment refers to these products staying in the hood reservoir and not spilling out into the space. "Minimum capture and containment" is defined as "the conditions of hood operation at which the exhaust flow rate is just sufficient to capture and contain the products generated by the appliance in idle and heavy load cooking conditions, or at any intermediate prescribed load condition."

During C&C testing, the exhaust rate was reduced until spillage of the plume was observed. The exhaust rate was then increased in fine increments until C&C was achieved. This threshold C&C rate was used for direct comparisons across scenarios, but was not performed in triplicate as prescribed in ASTM 1704.

Airflow Visualization

The primary tools used for airflow visualization were schlieren and shadowgraph systems, which visualize the refraction of light due to air density changes. Since the heat and effluent present on the appliance line changed the air density, the highly sensitive flow visualization systems provided a detailed image of the active area under the hood. The front and left lower edges of the hood were monitored by schlieren systems located at a height that was centered between the typical 36.0 inch appliance height and the typical canopy hood height of 78.0 inches above the floor. The right lower edge of the hood was monitored using a shadowgraph system, located at the same height as the hood edge. Other flow visualization tools used to see the thermal plume included smoke sticks and theater fog.

Figures 19-21 shows three images of three ovens under the wall-mounted canopy hood while exhausting 3400 cfm. The setup view in Figure 19 shows the ovens at 6.0 inches of front overhang, as viewed from the location of the schlieren optical unit. Figure 20 is a schlieren view indicating spillage when the oven doors were opened. Figure 21 is another schlieren view showing capture and containment was achieved by positioning the ovens at 18.0 inches of front overhang with the same 3400 cfm exhaust rate with the oven doors opened.

Figure 19. Setup View of Three Ovens under a Wall-Mounted Canopy Hood with 6.0 inches of Front Overhang

Figure 20. Schlieren View showing Spillage at an Exhaust Rate of 3400 cfm with 6.0 inches of Front Overhang

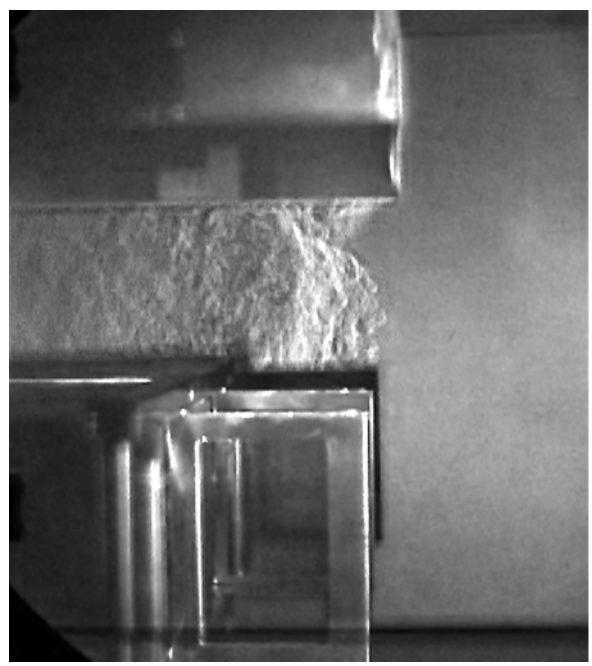

Figure 21. Schlieren View showing C&C at an Exhaust Rate of 3400 cfm with 18.0 inches of Front Overhang

2. Results and Discussion

Effect of Range Top Diversity and Range Accessories on Capture and Containment Performance

The C&C exhaust rate for the 6-burner range top was evaluated with this appliance in the left end position under the hood, while a broiler and another range occupied the middle and right end position. However, for the range top diversity testing, these additional appliances simply were used to fill the space under the hood and were not turned on. Evaluations were made with the front, rear, left, right, or all six range top burners in operation at full input. Operating the range top with six burners required a minimum exhaust rate of 4700 cfm for C&C. Operating only the three front burners required 3600 cfm. Operating only the rear three burners required 2500 cfm. The 1200 cfm reduction between the front and rear burners was attributed to the increased distance from the plume to the lip of the hood and the more direct path from the rear burners to the filters. When only the two left burners were turned on, the C&C exhaust rate was 3000 cfm. When only the right two burners were on, the C&C exhaust rate was 2500 cfm. The 500 cfm decrease found when operating the right burners instead of the left burners was due to the increased distance to the side of the hood. These tests also showed that a percentage of the total appliance input does not necessarily correlate to an equal percentage of the required exhaust rate to maintain C&C performance. A summary of the results is shown in Figure 22.

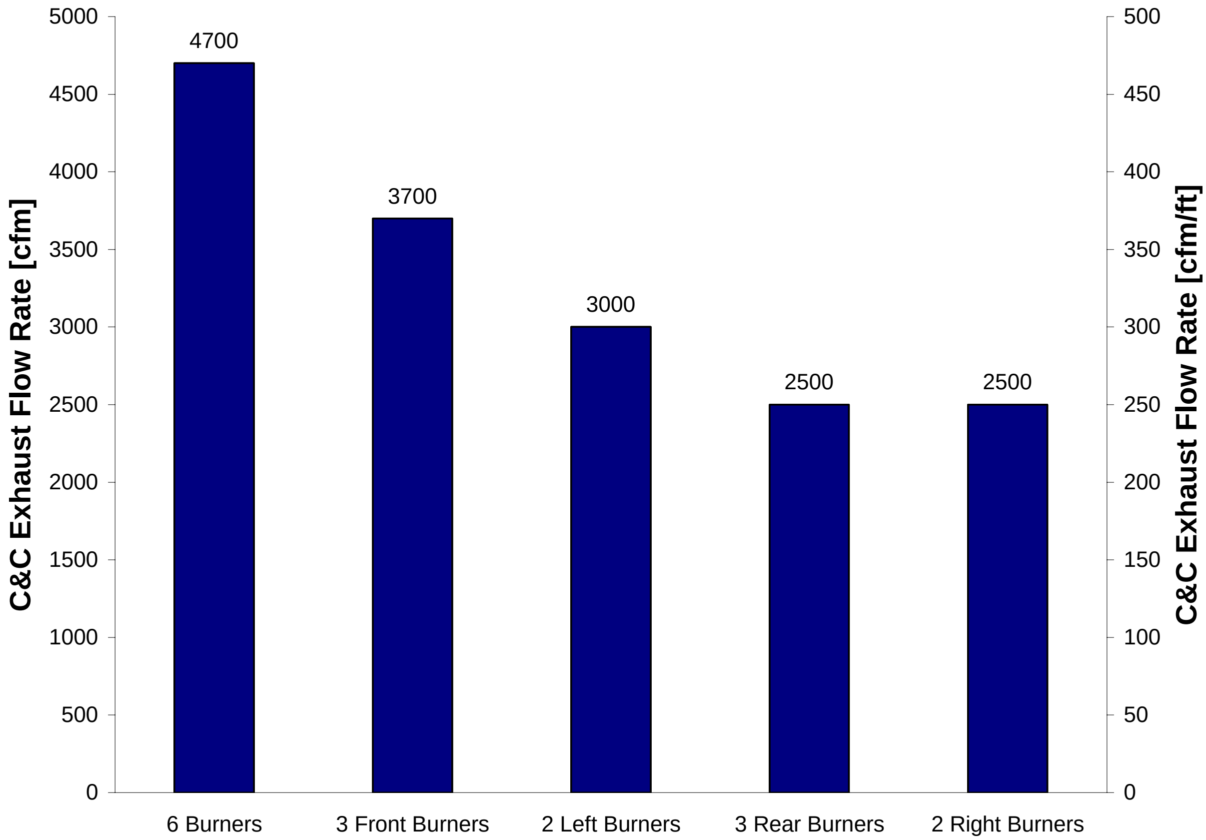

Figure 22. C&C Exhaust Rate as a Function of the 6-Burner Range Diversity

The installation of shelving above an appliance has anecdotally been thought to hinder hood performance. Furthermore, when shelving was installed, it was believed that tubular construction would affect hood performance less than solid construction. However, published data did not exist to qualify this hypothesis. For this investigation, a shelf measuring 36.0 inches wide by 12.0 inches deep, by 1.3 inches tall was centered left to right over the 6-burner range. The top of the shelf was located 54.0 inches above the floor, which corresponded to 18.0 inches above the cooking surface. Six 1.2-inch tubes spanned the width of the shelf and were spaced 2 inches apart. To convert the tubular shelf to a solid shelf, a sheet metal enclosure was installed over the tubes. Figures 23 to 32 show line drawings, set-up pictures, and schlieren images of shelving over the 6-burner range.

Figure 23. Front View of Appliance-Mounted Solid Shelf over 6-Burner Range Evaluation

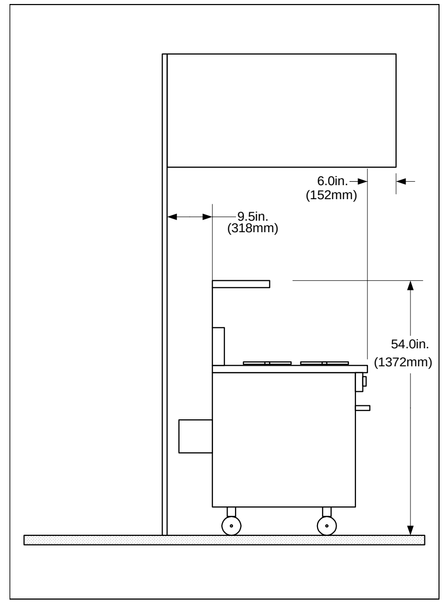

Figure 25. Line Drawing of Appliance-Mounted Solid Shelf over 6-Burner Range

Figure 24. Side View of Appliance-Mounted Solid Shelf over 6-Burner Range

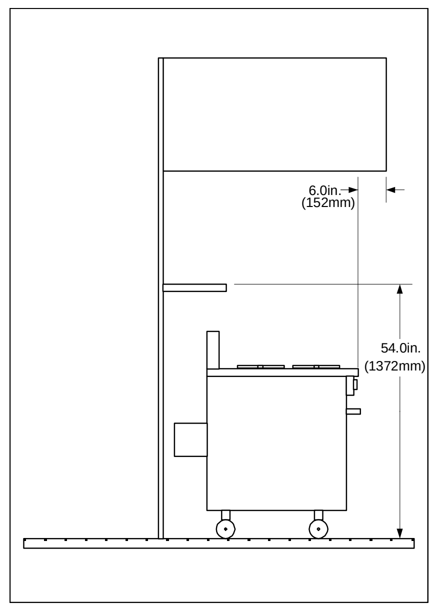

Figure 26. Line Drawing of Wall-Mounted Solid Shelf over 6-Burner Range

Figure 27. Close-up of Wall-Mounted Tubular Shelf over 6-Burner Range

Figure 28. Close-up of Wall-Mounted Solid Shelf over 6-Burner Range

Figure 29. 6-Burner Range without Shelf as Viewed from the Side Schlieren System

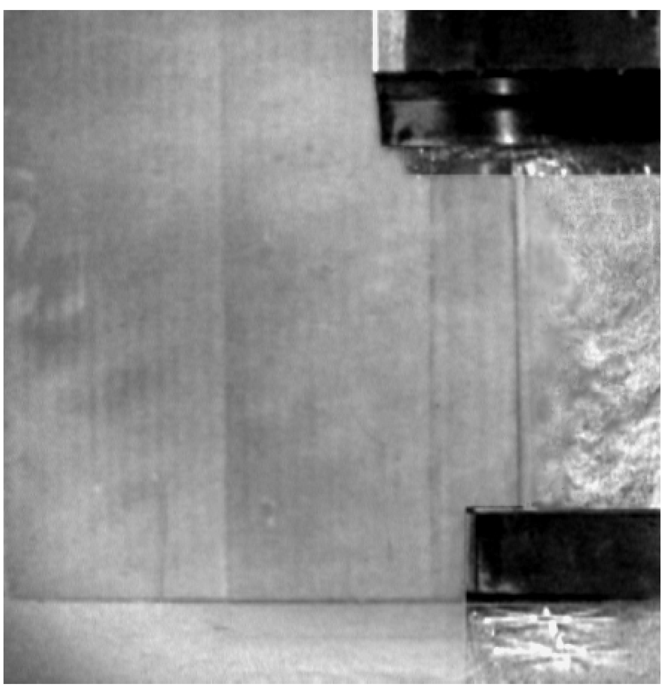

Figure 30. C&C while Hood was Exhausting 4700 cfm with 6-Burner Range at 100% Input and without Shelf

Figure 31. 6-Burner Range with Solid Shelf Mounted on Appliance as Viewed from the Side Schlieren System

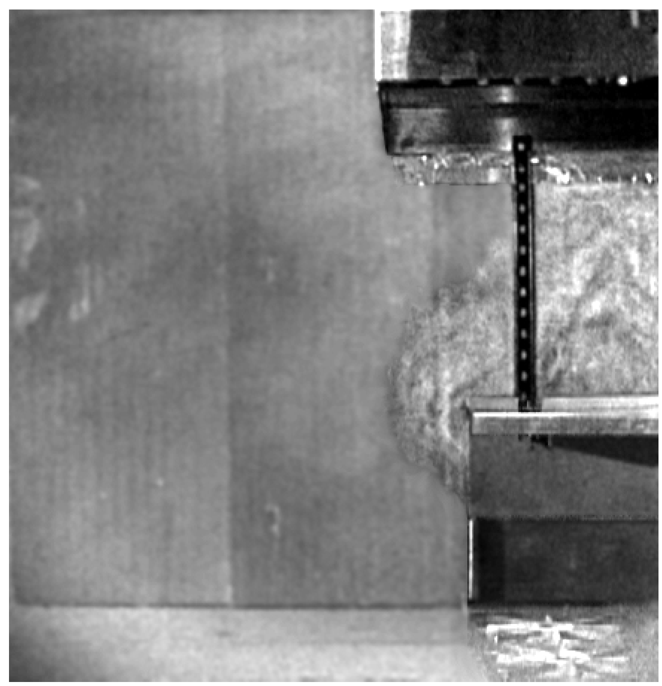

Figure 32. C&C while Hood was Exhausting 4600 cfm with 6-Burner Range at 100% Input and Appliance-Mounted Solid Shelf

Contrary to the expectations of the research team, C&C performance improved slightly with the installation of most shelf configurations over the 6-burner range because the plume could either travel upward with minimal interference, or could tightly wrap around the shelf and be directed toward the filters. The only exception was the installation of a solid shelf with only the rear three burners in operation. With 6-burners in operation, an 11% or 500 cfm reduction (from 4700 cfm to 4200 cfm) was observed with the wall-mounted tubular shelving. The shelf may have helped by reducing the volume of air coming up from behind the range and increasing the volume of air coming from the perimeter of the hood. When the three rear burners were in operation, the appliance-mounted solid shelf had negative impact on performance. Since the shelf was directly over the rear burners, the effluent plume was pushed out along the shelf's bottom. Without the front burners in operation to help turn the plume upward, the exhaust rate required a 500 cfm or 20% increase, from 2500 cfm to 3000 cfm. A summary of the data is shown in Figure 33.

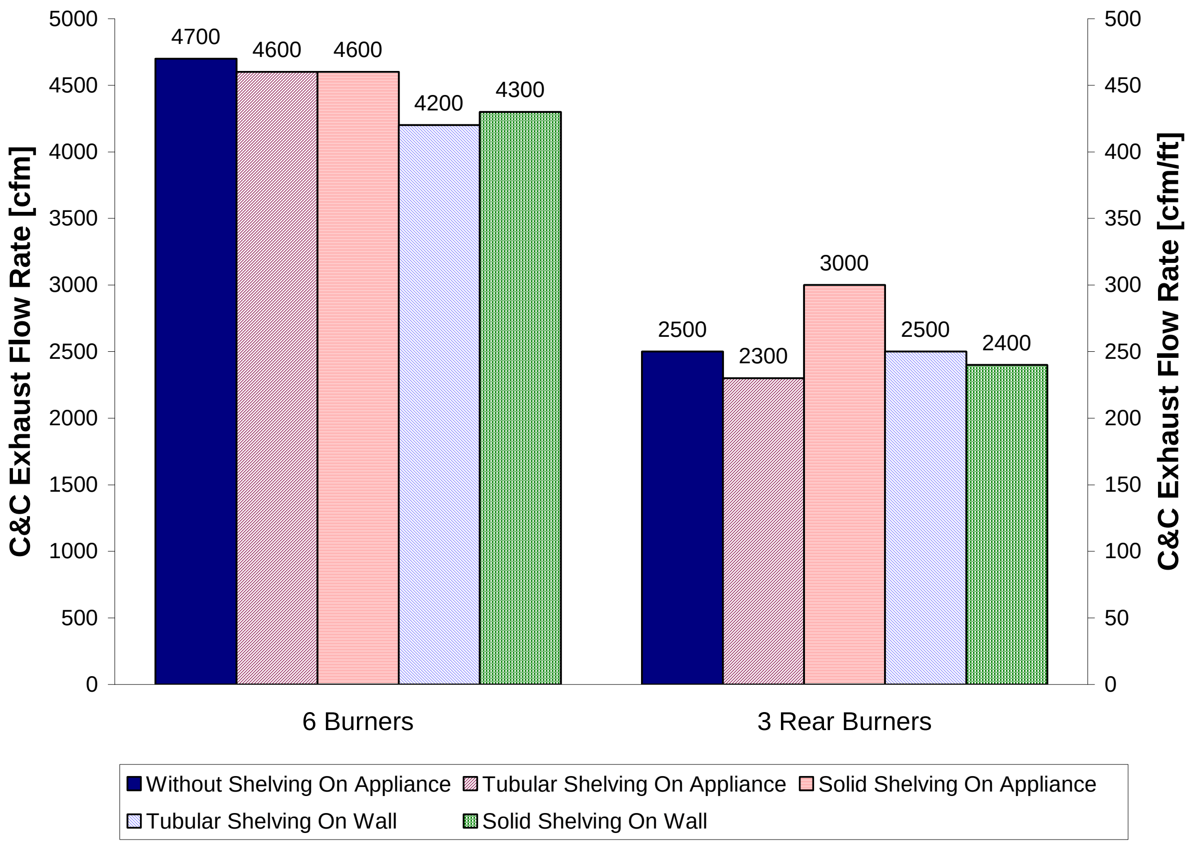

Figure 33. C&C Exhaust Rates for All Shelving Configurations Tested above the 6-Burner Range with either 6-burners or Three Rear Burners in Operation

Similar to shelving installed above cooking equipment, the installation of ancillary equipment like a salamander or cheese melter was thought to challenge the ability of a hood to capture and contain the thermal plume generated by the appliance underneath. To confirm or refute this effect, a gas-fired salamander was installed above the range and was positioned to provide 6.0 inches of left side overhang. To compare wall-mounted and appliance-mounted configurations, its mounting rack was slid into position and sheet metal inserts were installed to prevent the plume from traveling behind the salamander. Set-up and schlieren images are shown in Figures 34 to 36.

Figure 34. Set-up of Appliance-Mounted Salamander

Figure 35. Left Edge Set-up View of Appliance-Mounted Salamander under the Wall-Mounted Canopy Hood

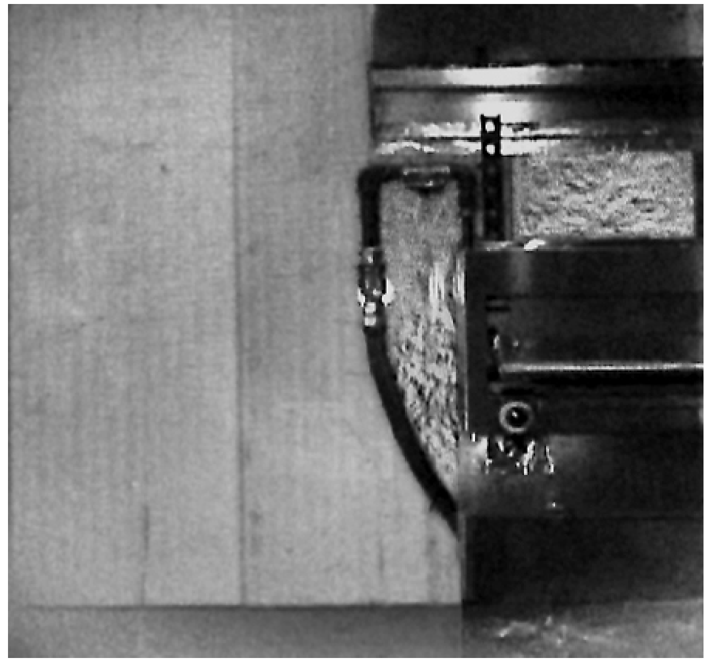

Figure 36. Schlieren View of Appliance-Mounted Salamander at C&C Conditions under the Wall-Mounted Canopy Hood

Overall, the salamander did not significantly affect the required C&C exhaust rate. For 6-burner and three front burner operation, the exhaust rate decreased as much as 400 cfm or 9% with the salamander installed. Furthermore, comparing the exhaust rates required for the salamander to the solid shelf shows that they both affect the exhaust rates to virtually the same degree.

In all but one case, it was best to mount the salamander on the wall, rather than on the appliance. With the salamander mounted on the wall, its plume was closer to the hood filters and farther away from the front edge of the hood, which aided C&C performance. The plume from the 6-burner range was also easier to capture and contain, since the wall-mounted salamander did not disrupt its flow. In some cases, the wall-mounted salamander appeared to act as a rear seal, which helped draw air from the front and sides of the cooking equipment, rather than from the gap behind the appliances. Figure 37 summarizes the exhaust rates required for the appliance-mounted and wall-mounted salamander over a 6-burner range.

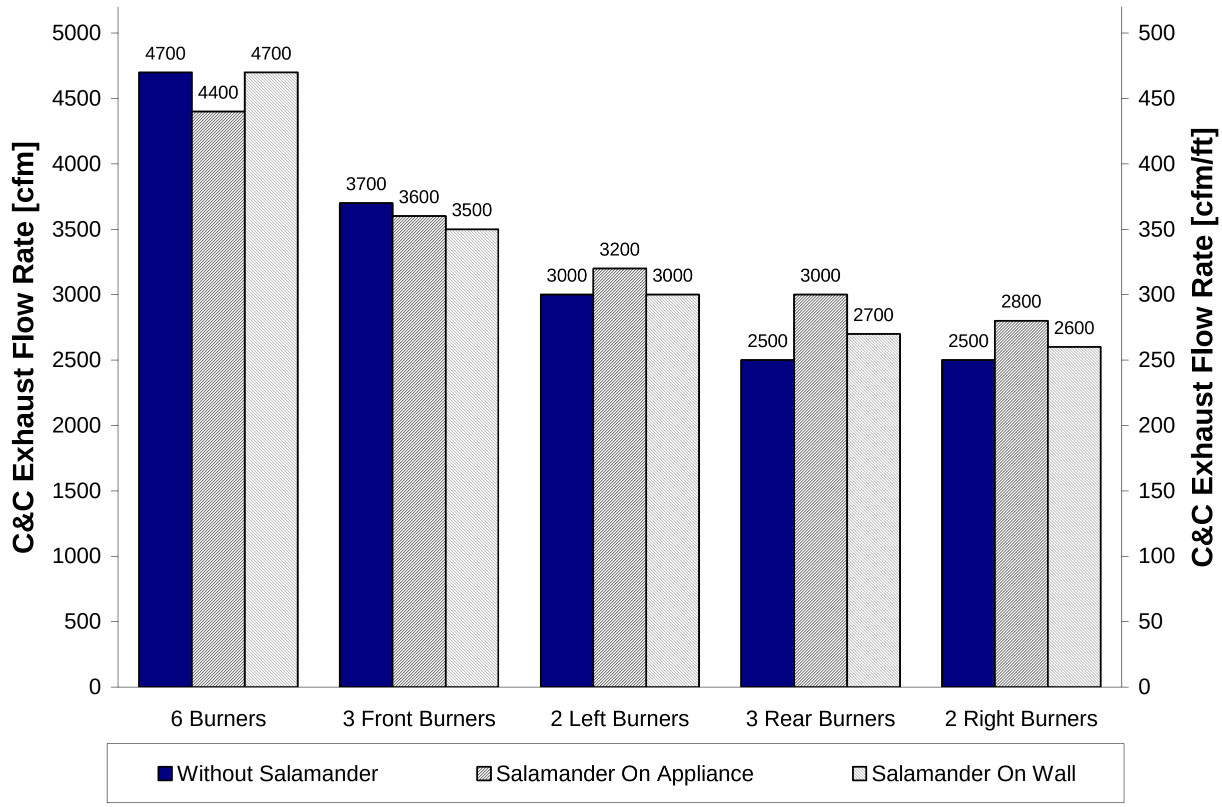

Figure 37. C&C Exhaust Rates for Wall and Appliance-Mounted Salamander over 6-Burner Range

Effect of Hood Depth on Capture and Containment Performance

Maximized front overhang of a canopy hood, which could also be stated as minimized rear clearance, has proven to improve the C&C exhaust rate in most cases. For a given depth of canopy hood (e.g., 4 feet), increasing the front overhang while decreasing the rear gap is accomplished by pushing an appliance as close to the back wall as possible, rather than aligning the front of each piece of equipment at a fixed overhang (e.g., 6.0 inches). In some cases, particularly for full-size convection or combination ovens, a 4-foot deep, wall-mounted canopy hood does not permit the equipment to be pushed back very far. In the case of the convection oven used for this research study, an additional 3.0 inches could be attained (over the minimum 6 inch overhang) for a total of 9.0 inches by eliminating all rear clearance to the transparent plastic wall. For large ovens, this amount of overhang could be considered marginal, as it creates a C&C challenge for the hood when the oven door is opened.

Once an appliance has been pushed back as far as possible, the only way to further increase front overhang is to make the hood deeper (e.g., 5 feet vs. 4 feet). Although this is recognized by the CKV industry as being a positive hood attribute, there is no published data comparing different depths of hoods when challenged by the same battery of equipment. To facilitate such a comparison, the 4-foot hood was converted into a 5-foot deep hood by extending the sides and top, as discussed in the Experimental Design section of this report.

This modified 5-foot hood was tested using four different appliance lines. The first was a multi-duty line, which was comprised of a light-, a medium-, and a heavy-duty appliance. The other three lines comprised three like-duty appliances in the light-, medium-, and heavy-duty categories. For all tests, the left and right overhang dimensions were held constant for each appliance line and the front overhang was varied from a minimum of 6.0 inches to the maximum possible for the respective appliance line. Examples are shown in Figures 38 to 41.

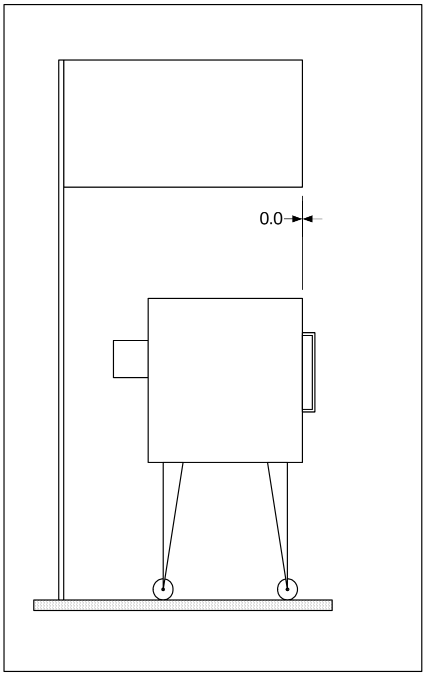

Figure 38. Line Drawing of 0 inch Front Overhang for the Full-Size Oven Using a 4-Foot Deep Hood

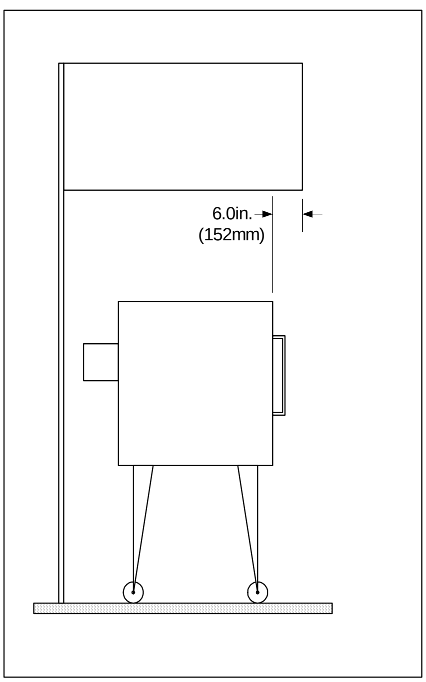

Figure 39. Line Drawing of 6.0 inches of Front Overhang for the Full-Size Oven Using a 4-Foot Deep Hood

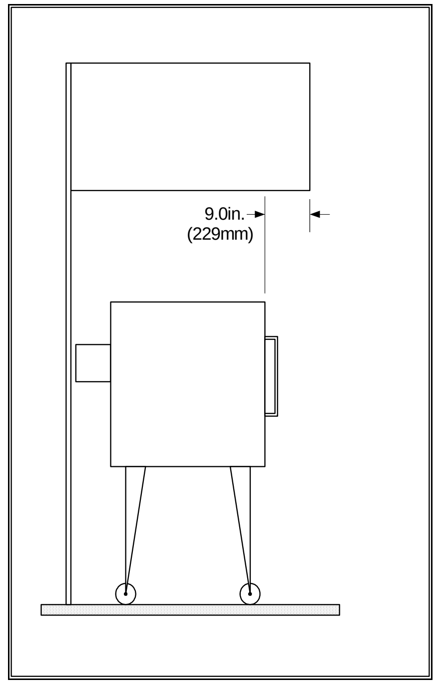

Figure 40. Line Drawing of 9.0 inches of Front Overhang for the Full-Size Oven Using a 4-Foot Deep Hood

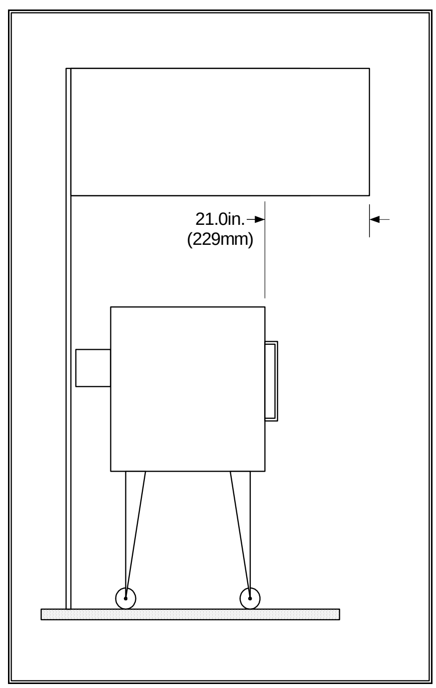

Figure 41. Line Drawing of 21.0 inches of Front Overhang for the Full-Size Oven Using a 5-Foot Deep Hood

Multi-Duty Appliance Line

The multi-duty appliance line, which consisted of a fryer, broiler, and oven, clearly demonstrated the benefit of maximizing front overhang. When all appliances were lined up for a 6.0 inch front overhang under the 5-foot deep hood, the C&C exhaust rate was 3900 cfm. This was significantly higher than the C&C rate of 2800 cfm for the 4-foot hood with a 6.0 inch overhang. However, when the cook line was pushed back to provide an 18.0 inch front overhang and reduce the rear gap accordingly, the C&C exhaust rate dropped to 2600 cfm. This was slightly lower than 2800 cfm for 4-foot hood with similar rear clearance and a 6.0 inch overhang. By further pushing each individual appliance back to its maximum front overhang and having a slightly staggered appliance line, the C&C exhaust rate dropped to 1900 cfm. When side panels were added to this configuration, the lowest C&C exhaust rate of 1700 cfm was recorded. Comparing the 4-foot and 5-foot deep hoods found the exhaust rates required for C&C were more dependent on the clearance from the back of the appliances to the wall than the front overhang dimension. Setup and schlieren images illustrating the advantage of pushing the appliances as far back as possible are shown in Figures 43 to 48. The results are summarized in Figure 42.

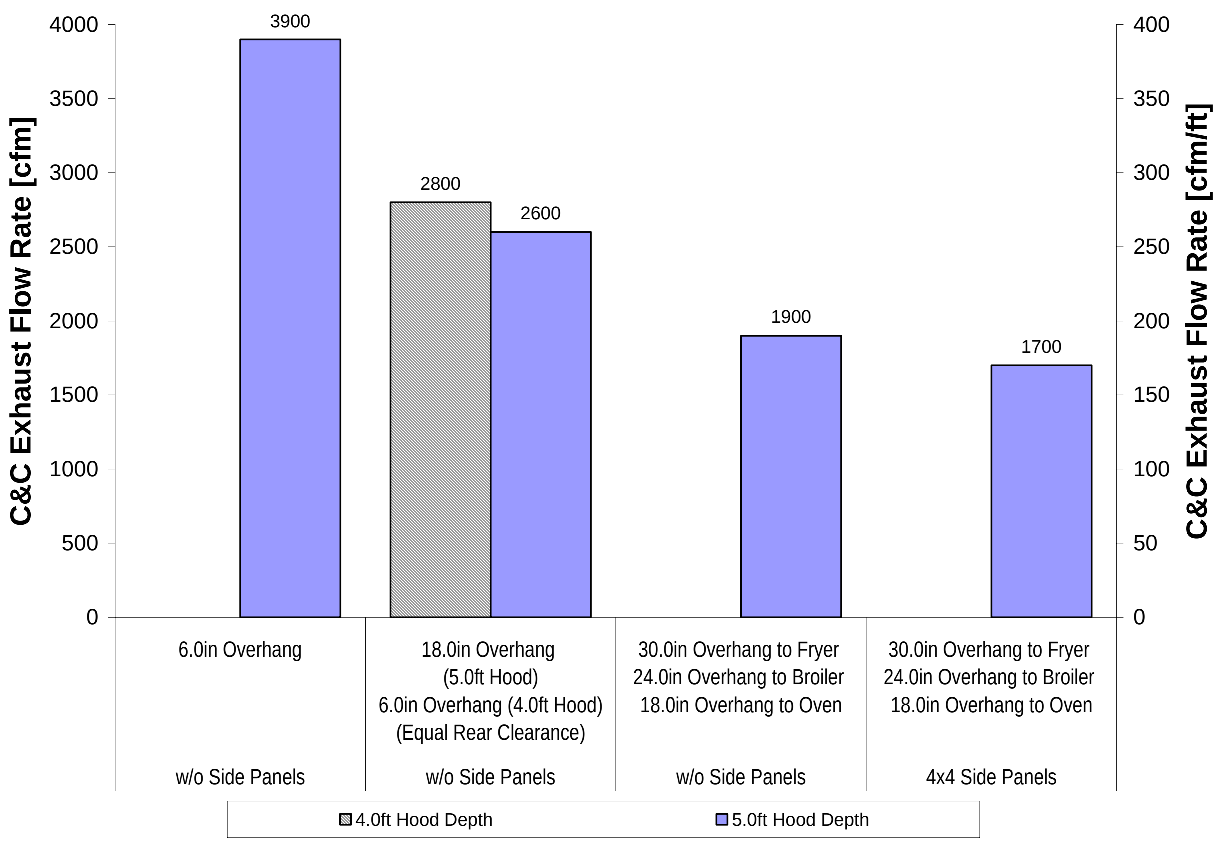

Figure 42. C&C Exhaust Rates for the 5-Foot versus 4-Foot Hood with a Multi-Duty Appliance Line

Figure 43. Set-up of a Fryer, Broiler, and Oven, under the 5-Foot Deep Wall-Mounted Canopy Hood with 6.0 inch Front Overhang during C&C Conditions at 3900 cfm

Figure 45. Set-up of a Fryer, Broiler, and Oven, under the 5-Foot Deep Wall-Mounted Canopy Hood with 6.0 inch Front Overhang during Spill Conditions at 1900 cfm

Figure 47. Set-up of a Fryer, Broiler, and Oven, under the 5-Foot Deep Wall-Mounted Canopy Hood with Maximum front Overhang for Each Appliance during C&C Conditions at 1900 cfm

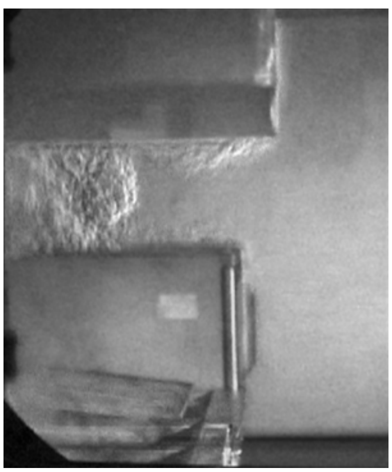

Figure 44. Schlieren Image of a Fryer, Broiler, and Oven, under the 5-Foot Deep Wall-Mounted Canopy Hood with 6.0 inch Front Overhang during C&C Conditions at 3900 cfm

Figure 46. Schlieren Image of a Fryer, Broiler, and Oven, under the 5-Foot Deep Wall-Mounted Canopy Hood with 6.0 inch Front Overhang during Spill Conditions at 1900 cfm

Figure 48. Schlieren Image of a Fryer, Broiler, and Oven, under the 5-Foot Deep Wall-Mounted Canopy Hood with Maximum Overhang for Each Appliance during C&C Conditions at 1900 cfm

Oven Line

For the three oven tests, it was again found that during normal operations with the doors closed, the rear clearance to the appliances was the determining factor. The 1200 cfm exhaust requirement found for the 4-foot hood depth was identical to the 1200 cfm exhaust requirement found for the 5-foot hood depth when the rear clearance was maintained at 1.5 inches. Similarly, for one oven the 650 cfm exhaust requirement found for the 5-foot hood depth was close to the 550 cfm exhaust requirement found for the 4-foot hood depth when the rear clearance was maintained at 1.5 inches.

The major finding for the three-oven line was the improvement possible with increased front overhang when the oven doors were opened. The required exhaust rate was 5800 cfm and 5200 cfm for the 5-foot and 4-foot deep hoods, respectively, when the ovens were set at 6.0 inches of front overhang. Using the additional hood depth available only with the 5-foot deep hood, the ovens were then pushed back to 18.0 inches of front overhang. In this location, the exhaust rate required with the oven doors open was 3400 cfm. Since the rear clearance was equal to the 4-foot hood with 6.0 inches of front overhang, it can be stated that the increased front overhang directly contributed to a 42% improvement in C&C performance when the oven doors were open. The same strategy yielded similar results for one oven. In this case, the C&C exhaust rate for the 5-foot deep hood was reduced from 5500 cfm to 3000 cfm, or 45%, compared to 4800 cfm for the single oven under the 4-foot deep hood. Set-up and schlieren images are shown in Figures 50 to 53. The results are summarized in Figure 49.

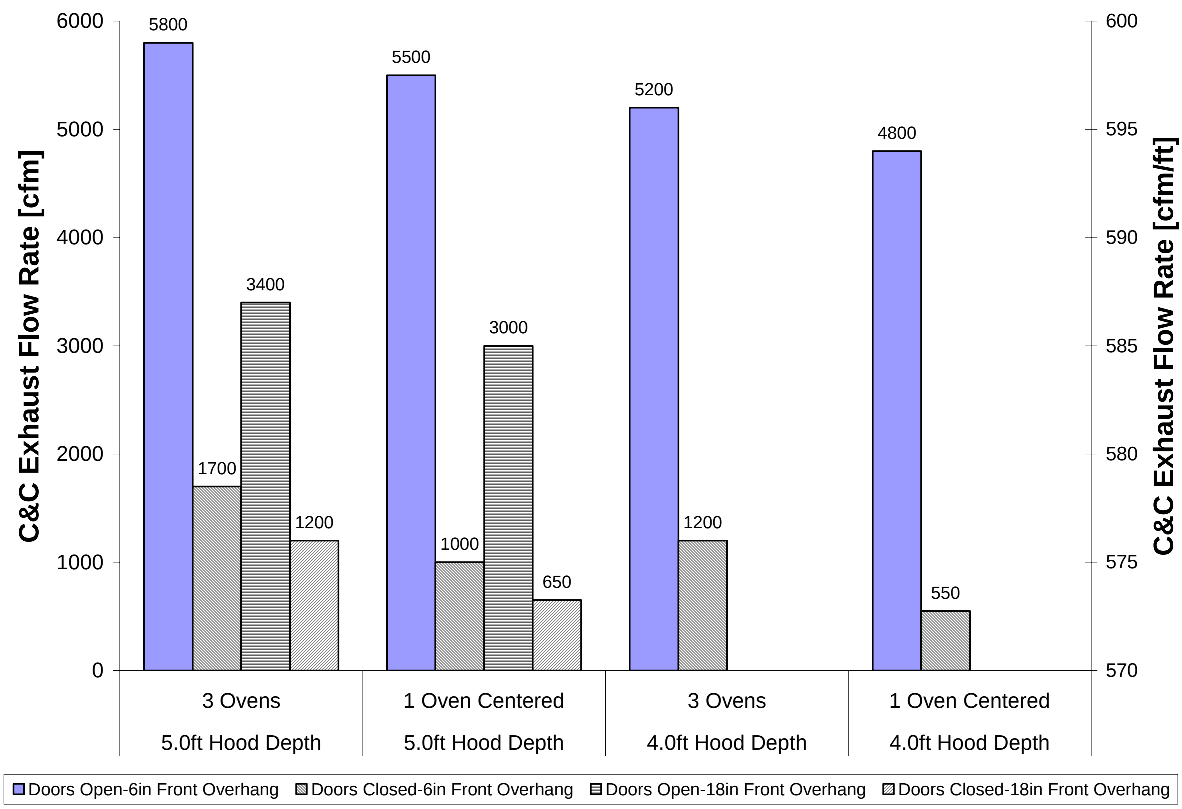

Figure 49. C&C Exhaust Rates for the 5-Foot versus 4-Foot Hood for a Light-Duty Oven Line

Figure 50. Set-up of Three Ovens under a 4-Foot Deep Wall-Mounted Canopy Hood at 6.0 inches of Front Overhang

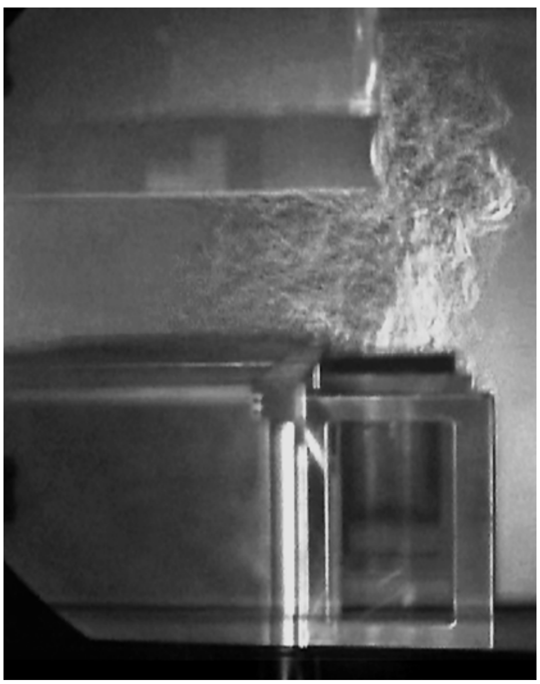

Figure 51. Schlieren Image of Three Ovens under a 4-Foot Deep Wall-Mounted Canopy Hood at an Exhaust Rate of 3400 cfm Showing Spillage with 6.0 inches of Front Overhang

Figure 52. Set-up of Three Ovens under a 5-Foot Deep Wall-Mounted Canopy Hood at 18.0 inches of Front Overhang

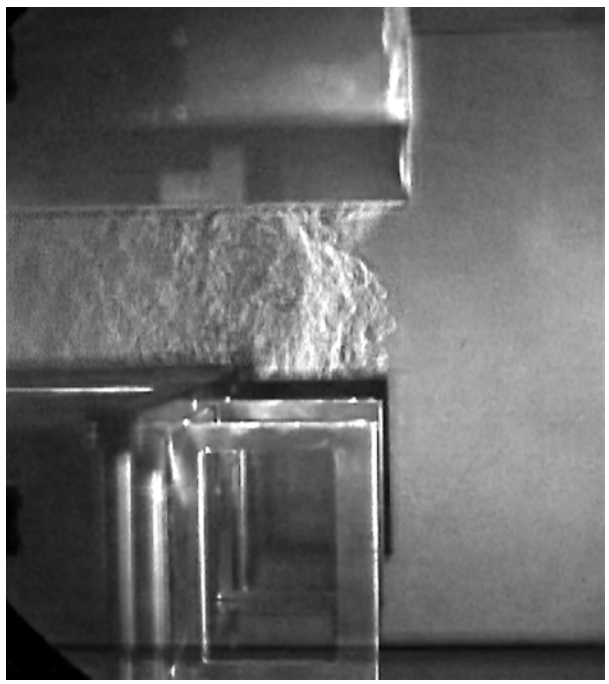

Figure 53. Schlieren image of Three Ovens under a 5-Foot Deep Wall-Mounted Canopy Hood at an Exhaust Rate of 3400 cfm Showing C&C with 18.0 inches of Front Overhang

Fryer Line

For the three 2-vat fryers, it was consistently found that increasing the front overhang for a given hood depth had a positive impact on C&C performance. For the 4-foot hood depth, the 3300 cfm required for a 6.0 inch front overhang was reduced to 2800 cfm with a 12.0 inch front overhang, and 2400 cfm with an 18.0 inch front overhang. This was an overall improvement of 900 cfm, or 27%. Another significant improvement was made when side panels were added. With the side panels installed and the front overhang maximized, the exhaust rate required for C&C was 1600 cfm. Compared to the baseline, this was a 1700 cfm or 52% improvement. When comparing the 4-foot and 5-foot hood depths, it was again found that the rear clearance was best used to compare appliance line configurations, rather than front overhang. With 1.5 inches of rear clearance, the 5-foot hood required 2300 cfm, compared to 2400 cfm for the 4-foot hood. When side panels were added, the 5-foot hood required 1400 cfm, compared to 1600 cfm for the 4-foot hood. The results are summarized in Figure 54.

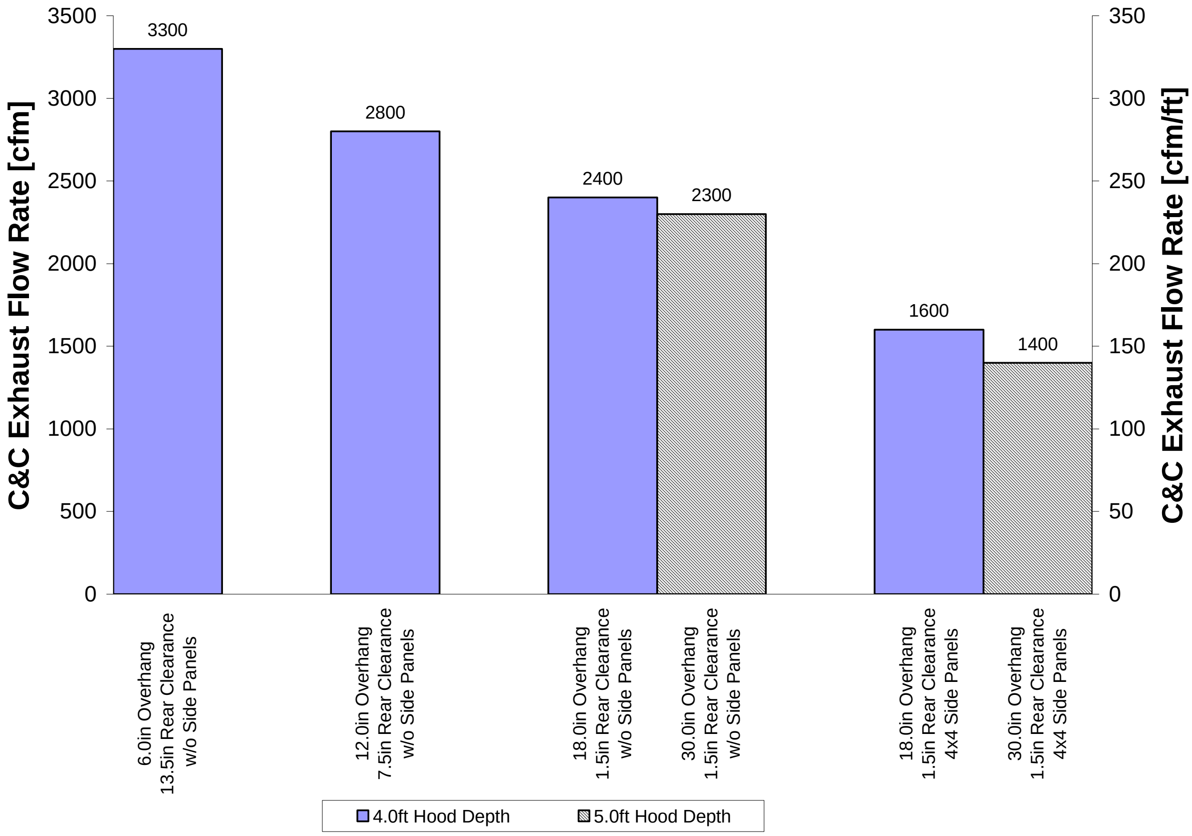

Figure 54. C&C Exhaust Rates for the 5-Foot versus 4-Foot Hood for a Medium-duty Fryer Line

Broiler Line

For the three broiler line, the advantage of increased front overhang and decreased rear clearance was repeated. However, when comparing the 4-foot and 5-foot hood depths, there was more of a difference between the C&C values at given rear clearance dimensions than for other appliance lines. Possibly, the larger reservoir was better able to accommodate the aggressive plume, which may have been better distributed along the full length of the filter bank. Additional investigations to optimize such a challenging appliance line included installation of a rear appliance seal and hood side panels.

For the 4-foot deep hood, 4400 cfm was required when the broilers were at a 6.0 inch front overhang. By maximizing the front overhang to 12.0 inches, the exhaust rate was reduced to 4000 cfm, which was a 400 cfm or 9% improvement. A rear seal was then evaluated with a minimum 6.0 inch front overhang. In the configuration shown in Figure 55, the C&C exhaust rate was 2900 cfm.

Figure 55. Rear Seal Evaluation with Three Broilers under a Wall-Mounted Canopy Hood at 12.0 inches of Front Overhang.

For the 5-foot deep hood, the required exhaust rate was reduced from 5700 cfm to 3500 cfm by increasing the front overhang from 6.0 inches to 18.0 inches. By maximizing the front overhang at 24.0 inches, the required exhaust rate was reduced to 2900 cfm, for an overall reduction of 2800 cfm or 49%. Adding a rear appliance seal reduced the exhaust rate to 2700 cfm and installing side panels with the rear seal reduced the exhaust rate to 2100 cfm. In total, a reduction of 3600 cfm or 63% was realized by optimizing the broiler cook line with the 5-foot hood. The results are summarized in Figure 56.

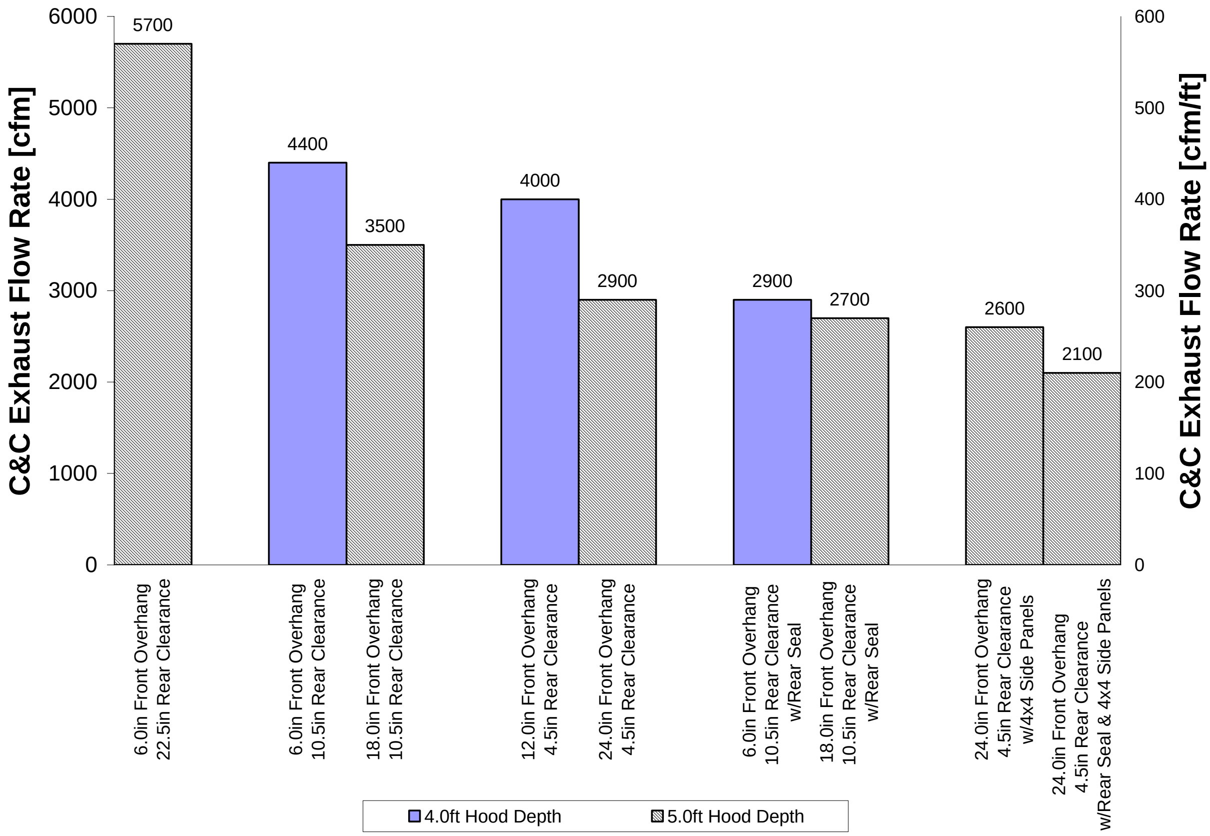

Figure 56. C&C Exhaust Rates for the 5-Foot versus 4-Foot Hood for a Heavy-Duty Broiler Line

Effect of Hood Reservoir Volume on Capture and Containment Performance

To evaluate C&C performance with various hood reservoir volumes, two different tests were performed. The first test evaluated adding a skirt to the standard 4-foot hood. The second test evaluated reducing the volume of the 5-foot deep hood to the volume of the original 4-foot deep dimension by installing a false ceiling within the hood.

The first test was performed with a 1-foot extension, or skirt, added to the bottom of the 4-foot hood. This modification resulted in a 3-foot hood height and increased the hood reservoir volume by 40 cubic feet or approximately 50%. However, to maintain a constant distance from the appliance to the hood, the broiler was lowered by one foot using an adjustable stand. The other two broilers were maintained at their standard height and were not turned on for the test. When the single broiler was operating in the left position, the results show a 4300 cfm exhaust requirement for the 2 foot hood height and a 4100 cfm requirement for the 3 foot hood height—not a very dramatic reduction. But when the broiler was operated in the center position, the results were 3100 cfm for the 2 foot hood height and 2000 cfm for the 3 foot hood height—a much more significant improvement with the taller hood. The 200 cfm or 5% improvement for the left appliance location indicated the key to C&C was not the hood volume, but rather the air velocity to turn the plume into the hood. In contrast, the 1100 cfm, or 35% improvement found for the center appliance position indicated the plume was well located in the hood. The increased hood volume allowed the plume to roll inside the hood and distribute itself more evenly along the filter bank, which led to the reduced exhaust rate requirement. The set-up is shown in Figure 57 and the results are summarized in Figure 58.

Figure 57. Set-up of 3 Foot Canopy Hood Height Testing with Broiler Operating in Left Position

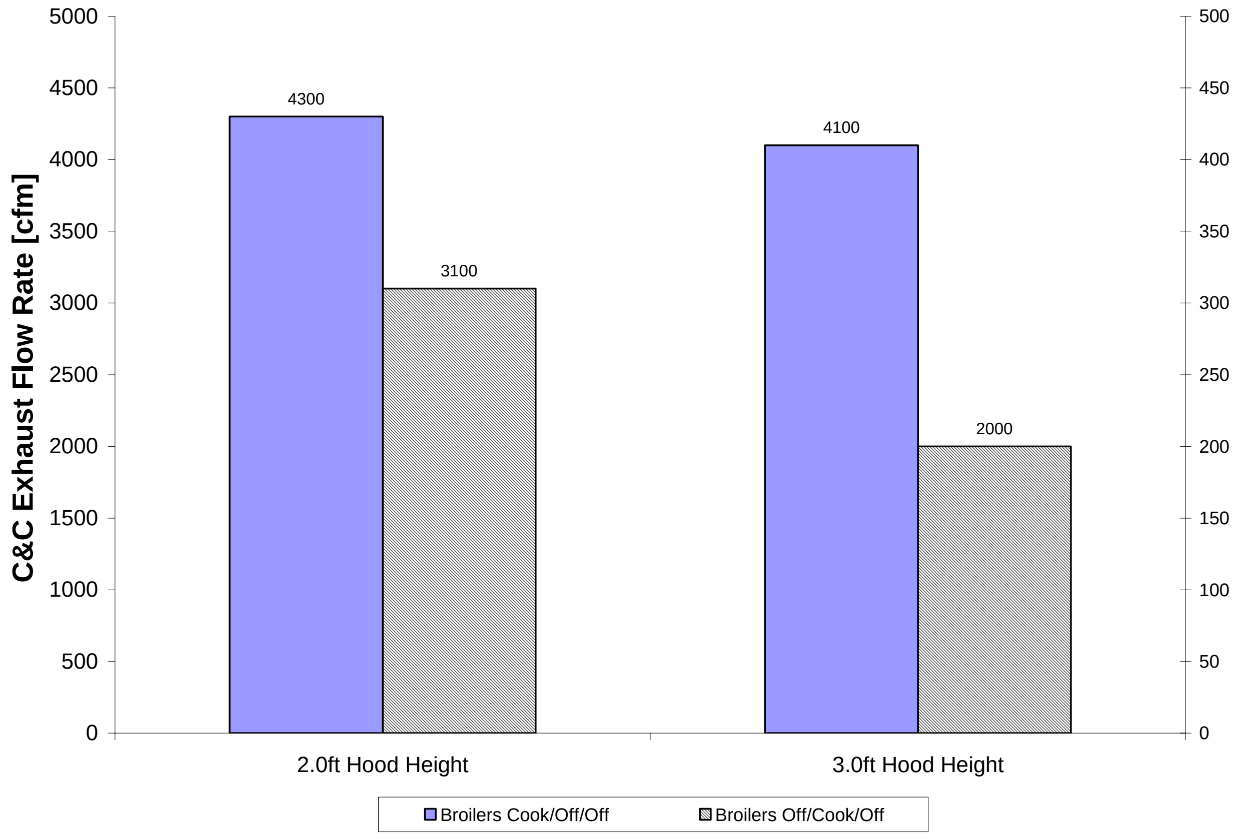

Figure 58. Evaluation of a 2 foot and 3 foot Hood Height with One Broiler

The second test evaluated reducing the volume of the 5-foot deep hood to the volume of the original 4-foot deep dimension by installing a false ceiling within the hood, as shown in Figure 59. The reduction in hood volume was 20 cubic feet, approximately 20% of the 5-foot reservoir. The remaining reservoir volume of the modified 5-foot hood approximately matched that of the 4-foot deep canopy hood, which allows direct comparison of hood depth performance without the potential performance changes due to changes in hood reservoir volume.

With the hood mounted at the standard height of 6.5 feet above the finished floor, all three broilers were used at their standard height. The results in Figure 60 show essentially no difference in hood C&C performance for the 10-foot by 5-foot by 2 foot canopy hood with two different reservoir volumes. However, the C&C performance improvements associated with increased front overhang, decreased rear clearance, and the installation of side panels were still apparent.

Figure 59. Set-up of Reduced Hood Reservoir Testing with Three Broilers in Operation

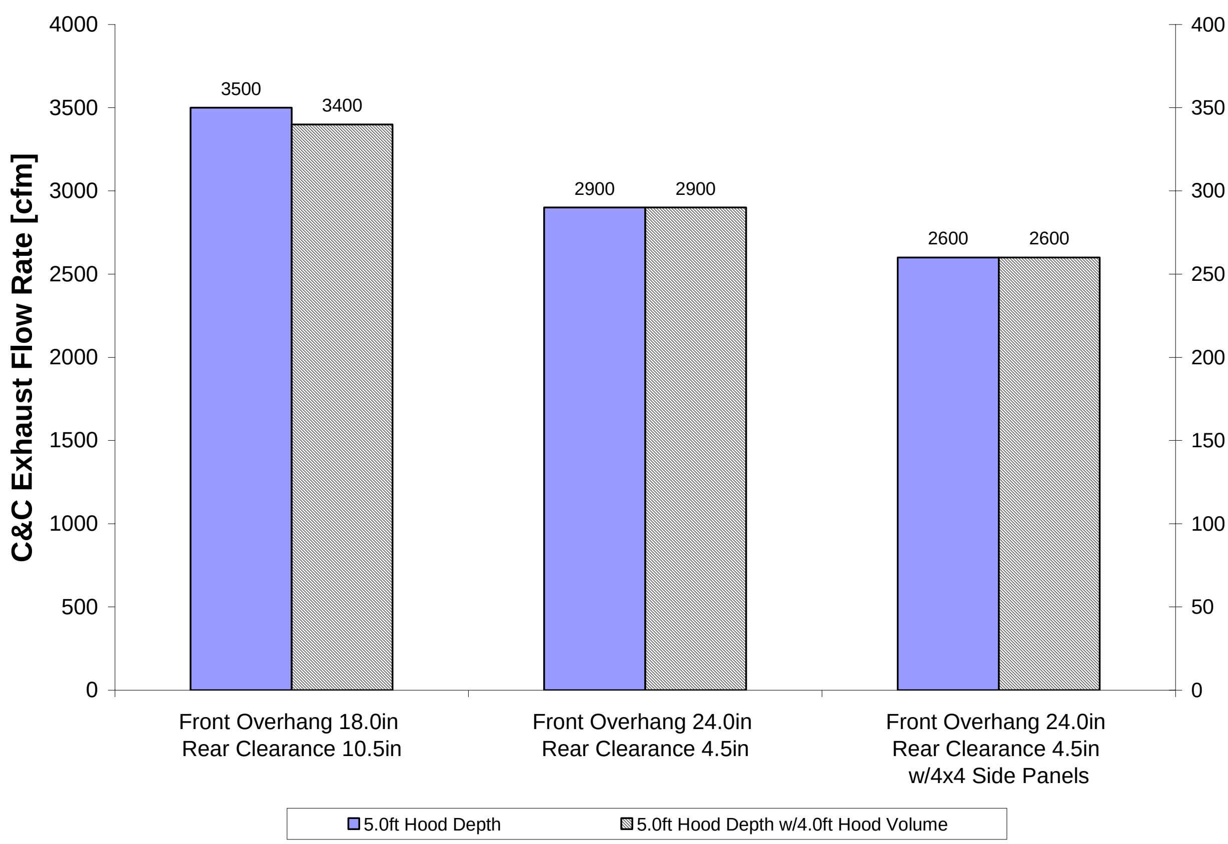

Figure 60. C&C Evaluation of Hood Volume with Three Broilers

Effect of Hood Mounting Height on Capture and Containment Performance

Within the CKV design community, it is generally believed that the greater the distance between the cooking surface of the appliance and the lower edge of the hood, the more difficult it is to capture and contain the plume. However, as with other parameters investigated in this supplementary study, there was no published data. To evaluate C&C performance at different hood mounting heights (and within the context of a sensitivity test versus an exhaustive study), one broiler was modified and attached to an adjustable stand, while the other two broilers were in position but not in operation. This adjustable broiler was then operated in either the left or center appliance position at five specific heights, as shown in Figure 61. The distance from the hood to the cooking surface was used to calculate an effective hood height above the floor. This indirect method of evaluating hood mounting height minimized the cost of testing and provided insight into this performance factor. The results are summarized in Figure 62.

Figure 61. Set-up of Effective Hood Mounting Height Test with Broiler Operating in Left Position

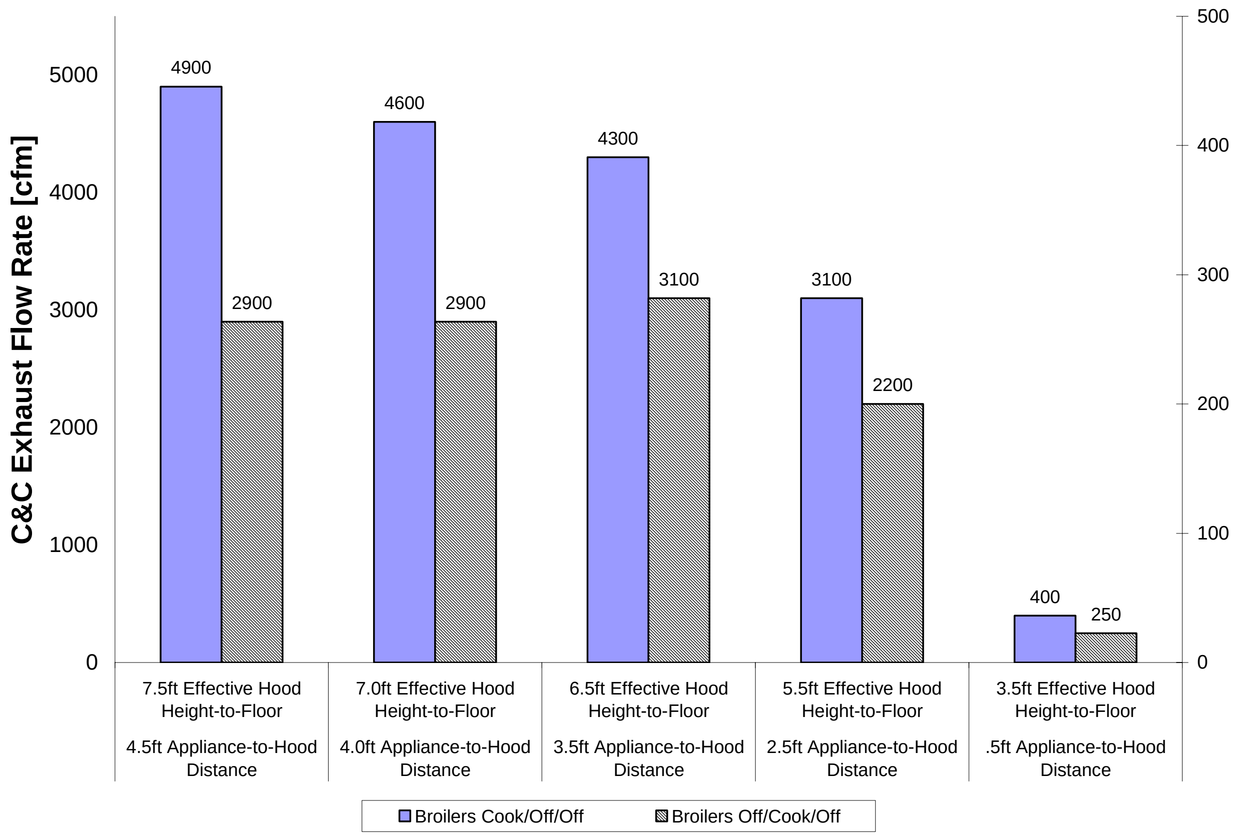

Figure 62. Hood Mounting Height Test Results using One Gas Broiler

When the broiler operated in the left position, C&C performance was directly related to the effective mounting height of the hood. Operating at the standard 6.5-foot hood height required 4300 cfm. When the effective hood height was increased to 7.0 feet and 7.5 feet, the exhaust rate increased to 4600 cfm and 4900 cfm, respectively. This was an increase of 300 cfm and 600 cfm, or 7% and 14%.

When the effective hood height was decreased to 5.5 feet (which could be possible with a proximity style hood design) the required exhaust rate decreased to 3100 cfm. This was a reduction of 1200 cfm, or 28% compared to operating at the standard hood height. An effective hood height of 3.5 feet was also evaluated, which resulted in a 6.0 inch distance from the appliance to the hood. While obviously not practical in the real world, this test height showed that the plume volume from the appliance could be captured and contained at the very low exhaust rate of 400 cfm. This 91% reduction in exhaust airflow supports the theory that bringing the lower edges of a hood closer to the cooking equipment and adding side panels can enhance hood performance. This concept is applied within the design of proximity, backshelf, and close coupled hoods and explains why the salamander did not impact C&C airflow rate when operated above the 6-burner range top.

When the broiler was operated in the center position, C&C performance was essentially unchanged at effective hood heights at or above the standard 6.5-foot height, which required 3100 cfm. When the effective height was decreased to 5.5 feet, the C&C exhaust rate dropped to

2200 cfm. This was a reduction of 900 cfm, or 29%. The 3.5-foot effective height required only 250 cfm, which was similar to the result found for the left position.

With the broiler in the center position, the C&C exhaust rates were always lower than for the broiler in the left position, emphasizing the importance of placing heavy-duty appliances in the center of the line. The center position was also less sensitive to increased hood height, which indicated that the expanding plume from the appliance was easier to capture and contain relative to the left appliance position. Similar performance improvements were found for both appliance positions when hood height was decreased, due to the improved draw of the closer hood on the appliance plume.

Effect of Hood Filter Height and Location on Capture and Containment Performance

The effect of the baffle filter height and position on hood performance was investigated with the gas range in the end position as a thermal plume generator. The exhaust C&C rate was determined for the standard 19.6 by 19.6 by 1.8 inch baffle type grease filters with an exposed height of 18.0 inches, as shown in Figure 63. The top or bottom halves of the exposed filter were then blanked and the capture and containment rates were compared to the standard configuration. The hood with filter blanks installed is shown in Figures 64 and 65.The data is summarized in Figure 66.

Figure 63. Canopy Hood with Factory Equipped Filters

Figure 64. Canopy Hood with 50% Filter Height at the Lower Location (upper portion blanked)

Figure 65. Canopy Hood with 50% Filter Height at the Upper Location (lower portion blanked)

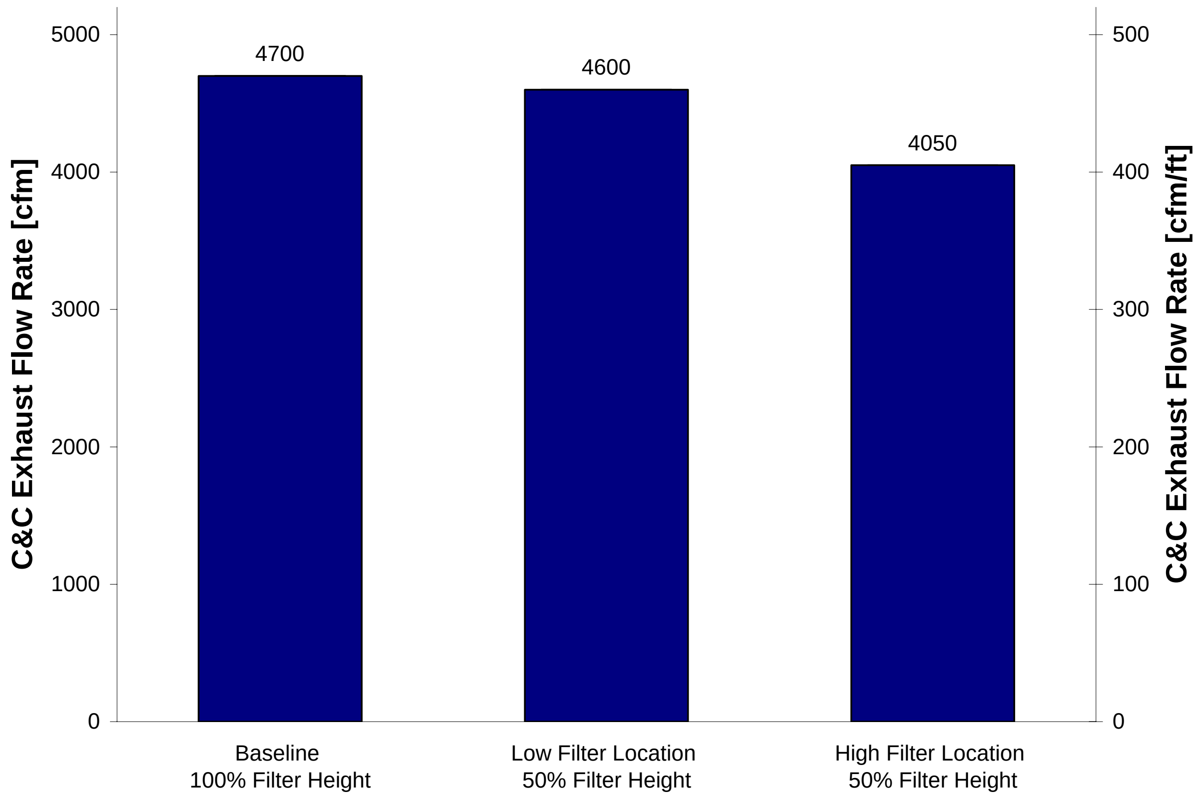

Figure 66. C&C Airflow Rates for 100%, Lower 50%, and Upper 50% Open Filter Height with 6-Burner Range in Operation at 100%

Filter size and location are believed to affect capture and containment performance. Blanking 50% of the original 18.0 inch filter height caused two changes to occur. It caused the 320 fpm face velocity through the 18.0 inch tall filter bank to roughly double at a given exhaust rate. It also relocated the 9.0 inch filter openings either higher or lower in the hood.

The lower filter location decreased the required exhaust rate by 100 cfm or 2%, compared to the original tall filter configuration. At the lower filter location, the filter face velocity increased to 630 fpm and the top of the 9.0 inch filter opening was 14.0 inches below the top of the hood.This location was not optimal for C&C performance.

The upper filter location provided a marked improvement in C&C performance, decreasing the required exhaust rate by 650 cfm or 14%, compared to the original tall filter configuration. At the higher filter location, the filter face velocity increased to 550 fpm and the top of the filter bank was 5.0 inches below the top of the hood. This configuration seemed have an advantage by not only coming closer to matching the high velocity thermal plume generated by the gas range, but also by evacuating the top of the hood reservoir where the hot plume collected.

3. Conclusions

This supplemental research to ASHRAE 1202 RP showed the importance of appliance usage and accessories, as well as hood dimensions (including overhang, reservoir volume and mounting height) with respect to hood capture and containment performance. Many of the general observations can be applied as best practices for designers, installers, and operators. These include:

- Positioning an appliance so that its thermal plume is inside the hood's perimeter as far as possible will improve C&C performance.
- Positioning heavy-duty appliances towards the center of a cooking equipment line will enhance capture and containment.
- Installing shelving or ancillary equipment such as a salamander behind or above an appliance typically will not have a detrimental impact on C&C performance, provided other best practices (e.g., maximizing hood overhang) are observed.
- Maximizing front overhang while minimizing rear clearance can greatly improve C&C performance.
- Specifying partial side panels will improve hood performance.
- Increasing hood depth (front-to-back) will improve C&C performance when this additional hood depth is used to maximize the front overhang dimension.
- A taller hood with increased reservoir capacity may improve C&C performance by allowing a concentrated plume to be more evenly distributed along the filter bank.
- Installing hoods at the lowest height practical (or permitted by code) to minimize the distance from the cooking surface to the hood will improve C&C performance.

Effect of 6-Burner Range Top Diversity and Accessories on Capture and Containment Performance

With the 6-burner range top positioned in the left end position under the hood, the required C&C exhaust rate varied significantly (from 250 cfm/ft to 470 cfm/ft) as a function of the location and number of burners being used. This variation implies that the design exhaust rate for a gas range top will be dependent on its usage in different food service operations. There will be applications where the range top is solidly in the heavy-duty category, while other times a medium-duty classification may be adequate.

Contrary to researchers' expectations, in all but one configuration tested, neither solid nor tubular shelving over the 6-burner range required an increase in the exhaust rate. In fact, tubular shelving mounted to the back of the appliance showed a slight enhancement when compared to having no shelving installed.

Also contrary to expectations, a gas-fired salamander positioned over the 6-burner range did not exhibit a negative effect on hood C&C performance. In all but one case, it was best to mount the salamander on the back wall rather than on the appliance. For 6-burner and 3-front-burner operation, the exhaust rate actually decreased when the salamander was installed.

Effect of Hood Depth on Capture and Containment Performance

Comparing the 4-foot and 5-foot deep hoods found a trend that was consistent for all tested cook lines - the exhaust rates required for C&C were more dependent on the clearance between the back of the appliances and the wall than the front overhang dimension. In some cases tested when the rear gap between the appliance and the wall was equal, there was no significant advantage in using the 5-foot deep hood over the 4-foot deep hood. When the front overhang was set to a minimum 6.0 inches, the 5-foot hood required significantly more exhaust than its 4-foot counterpart, due to the corresponding increase in gap between the appliance and the back wall.

The greatest advantage of the 5-foot over the 4-foot hood was its ability to capture and contain the plume when an oven door was opened, provided the 5-foot depth was used to maximize the front overhang. It also showed an advantage over the 4-foot hood in C&C performance over the heavy-duty gas broiler line, when the rear gap was minimized and the front overhang was maximized.

Effect of Hood Reservoir on Capture and Containment Performance

Increasing the reservoir volume by adding a 1-foot skirt to the lower edge of the hood and maintaining a constant distance from the broiler to the lower edge of the hood provided an effective way to evaluate the effect of increased hood reservoir volume. When the broiler was operated in the left appliance position, the increased hood volume demonstrated a marginal improvement in C&C performance. The 200 cfm or 5% improvement for the left appliance location indicated the key to C&C was not the hood volume, but rather the air velocity to turn the plume into the hood. In contrast, the 1100 cfm or 35% improvement found for the center appliance position was significant. This improvement indicated the plume was well located in the hood and the increased hood volume would allow the plume to roll inside the hood and distribute itself more evenly along the length of the hood's filter bank.

Decreasing the reservoir volume of the 5-foot deep hood to the approximate volume of the 4-foot deep hood did not affect the C&C performance when challenged by the three-broiler line. In this case, the greater hood depth affected the C&C requirement more than the reservoir volume with the lowered hood ceiling.

Effect of Hood Mounting Height on Capture and Containment Performance

Minimizing the hood mounting height had a positive effect on C&C performance. In most cases, a direct correlation could be made between the required exhaust rate and hood height for a given appliance line. Of interest to CKV system designers is the tradeoff when the 6.5-foot minimum mounting height for a canopy hood is increased to 7.0 or 7.5 feet. For the gas broiler installed at the end of the cook line, increasing the hood height by 1 foot required a 14% increase in exhaust rate. However, when the broiler was placed in the center position, the increased hood height did not compromise C&C performance or require a higher exhaust flow rate. As the hood-to-appliance distance was reduced below the standard 6.5-foot mounting height, dramatic reductions of the exhaust requirement were found. This exhaust reduction illustrates the potential for optimizing CKV systems through the application of close-coupled proximity hoods.

Effect of Hood Filter Height and Location on Capture and Containment Performance

Evaluation of the location and size of the hood filters was performed with one heavy-duty range operating at the end appliance position. The question was whether the taller filters with more open area or the shorter filters with the higher relative face velocity would have an advantage. The effect of locating the short filters either high or low in the hood was also evaluated. While this single data point cannot be used as a general statement, some observations were made.

- When located higher in the hood, shorter baffle filters showed a significant C&C exhaust rate reduction, compared to taller filters. In this configuration, the C&C exhaust rate was reduced from 4700 to 4050 cfm (470 to 405 cfm/ft), or 14%, with a 6-burner range operating at full input.
- When located low in the hood, shorter baffle filters reduced the C&C exhaust rate from 4700 to 4600 cfm (470 to 460 cfm/ft), or 2%.
- Overall, the shorter filters with the reduced filter face area and higher relative face velocities demonstrated improved C&C performance.

4. References

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Appendix A: Laboratory Description

The CKV laboratory located near Chicago was constructed to dimensions of a typical commercial kitchen. The structure consists of layered airtight walls and multiple airtight roof penetrations or “curbs” to which hoods and fans could be installed in various locations throughout the facility. The laboratory doors are custom fabricated and sealed to provide access to the room without allowing air leakage. An outside view is shown in Figure A-1.

Figure A-1. CKV Laboratory - Outside View

To ensure accurate and repeatable test results, the laboratory is equipped with state of the art metrology. An airflow measurement chamber with precise airflow measurement nozzles was installed on a single air supply system for the laboratory. Precise control of the air volume entering and leaving the test laboratory was achieved using variable speed drives on the hood’s exhaust fan, as well as the laboratory’s single supply fan. The laboratory control system automatically maintains a near zero differential pressure between inside and outside of the test laboratory. With the laboratory being airtight and the differential pressure at zero, it is known that the air volume entering the laboratory equaled the air volume leaving the laboratory. Therefore, airflow measurement can be on the clean supply air stream to protect the sensors.

The laboratory uses floor standing displacement ventilators along the wall farthest from the tested equipment as its main supply air system. This displacement ventilation strategy has proven to minimize the impact of the supply airflow on the hood's capability to capture effluent from the appliances. A secondary air supply system is available to study various independent MUA strategies. With this system, concepts such as short circuit hoods, as well as other hood local air supplies can be readily evaluated.

Figure A-2 shows the roof of the laboratory with the two supply and exhaust systems. Each system turns downward 90˚ to enter the airtight test space through a sealed penetration curb.

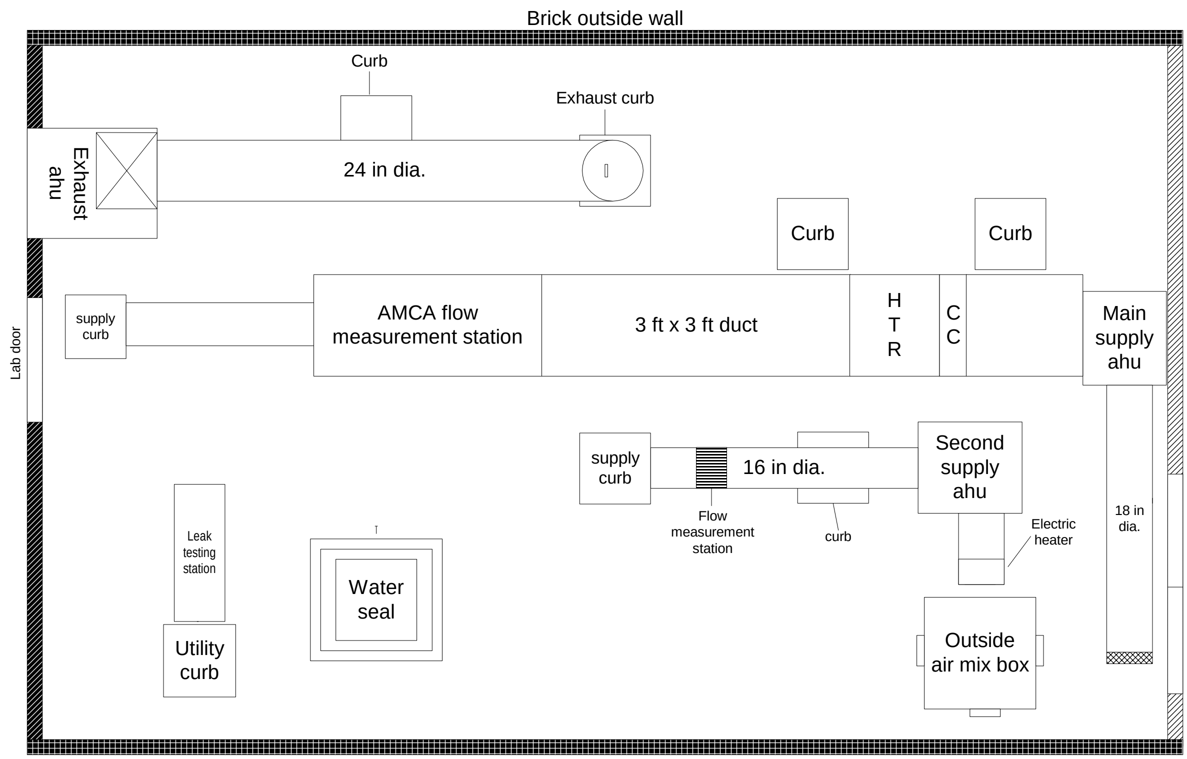

Figure A-2. Plan View of the Laboratory Roof with HVAC Equipment

A suspended ceiling hangs at a height of 9 feet, which is typical for commercial kitchens. Oversized strut type bracing is used to suspend the hood, ceiling, MUA ductwork, and portable backwall to allow for quick adaptability to the various test requirements. A portable backwall allows fast changing from a wall-mounted to an island mounted canopy hood. The 16 foot wide by 8 foot tall wall is constructed of clear plastic to accommodate the visualization systems, and mounts to a trolley system in the suspended ceiling.

Airflow Visualization

Focusing schlieren systems and shadowgraph systems are the primary tools used for airflow visualization. Schlieren systems visualize the refraction of light due to air density changes. The visual effect can be directly observed when looking over a hot road during the summer or at the exhaust of a jet engine. Using sophisticated optical technology, the laboratory schlieren flow visualization system amplifies this effect for lower temperature differences, providing higher sensitivity and contrast than what is seen by the naked eye. Figure A-3 is an example of what is seen with the naked eye compared to what can be seen from the same vantage point through a schlieren optical system. Shadowgraph systems also make use of the schlieren effect, providing similar sensitivity but with less contrast than schlieren visualization systems.

Figure A-3. Naked Eye and Schlieren Optical System Views of Two Idling Broilers, under Canopy Hood

Figure A-4 shows a plan view of the test setup and the flow visualization systems. One schlieren system is typically aligned to the front edge of the hood and another schlieren system monitors the rear or side edge of the hood. Both schlieren systems are located at a height that is half the distance between a typical 36.0 inch appliance height and a canopy hood mounted 78.0 inches above the floor. The left and right edges of the hood can be viewed using shadowgraph systems on portable stands. Generally, the shadowgraph systems were located at the same height as the hood edges being monitored.

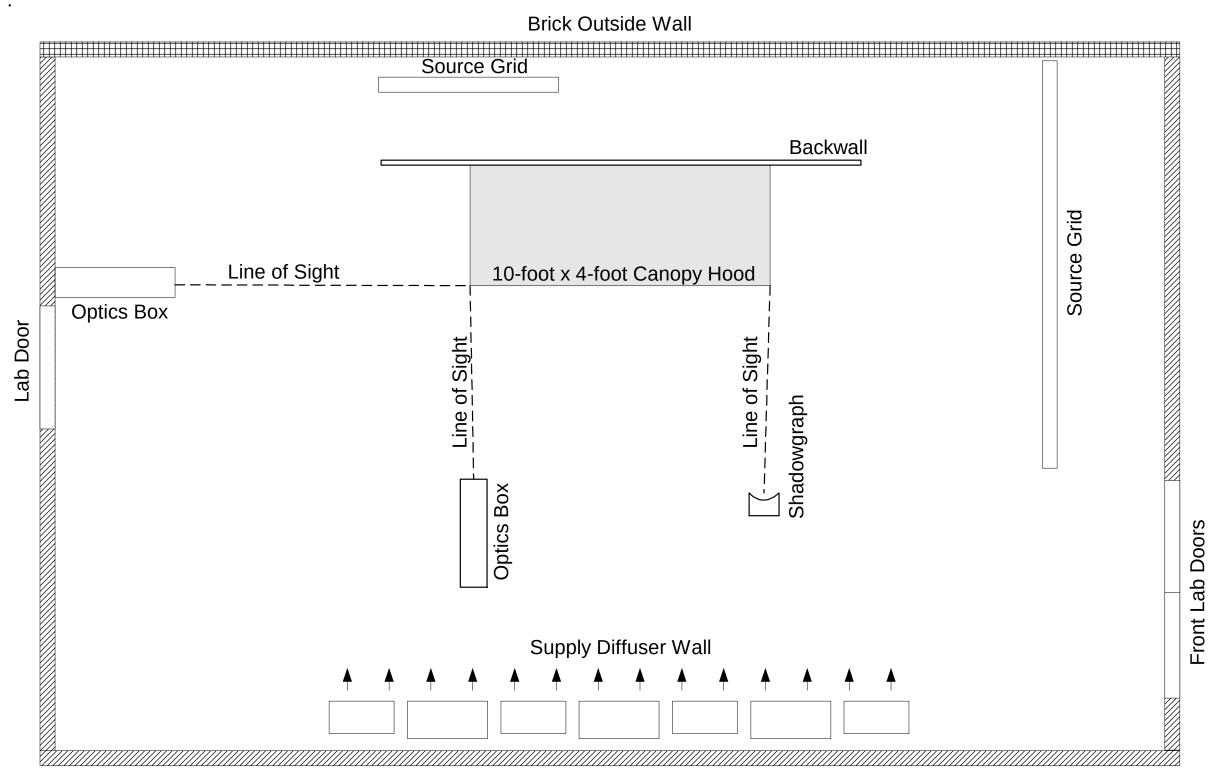

Figure A 4. Plan View of Flow Visualization Equipment Setup

Instrumentation and Control

The data acquisition system consists of various components communicating with a custom developed control program. The sensors interface with a modular data acquisition rack, capable of reading a wide range of input signals and providing control signals out to the equipment. Temperatures are monitored with an IEEE bus controlled high precision multimeter and scanner designed for high accuracy 4 wire 100 ohm platinum resistance thermal devices (RTD's). The system uses industry standard inputs including 4-20mA, 0-5VDC, pulse, and more to communicate with the data acquisition system. Equipment can be controlled through digital or analog output channels. The control program modulates the MUA supply system or exhaust blower to achieve the desired airflow rate and room pressure. All measured values during tests can be recorded to a single data file in designated time intervals.

The main supply's airflow measurement station, designed and installed in accordance with AMCA Standard 210/ASHRAE Standard 51 [Ref 11], contains three ASME specified precision spun aluminum nozzles, located on a board inside a fully welded chamber. The airflow through this chamber is calculated from the absolute pressure upstream before the nozzles combined with the measured differential pressure across the nozzles. The secondary supply's airflow measurement station utilizes the pressure drop across a pitot array station to determine the airflow rate. Dew point and dry bulb temperature of the supply air streams are also measured to allow conversion of the calculated airflows to standard conditions.

Temperatures are measured every few seconds and recorded. Measured points include; natural gas temperature, cooking process, appliance surface, and hood surface temperatures. An equal area concentric array of 12 RTD's is located in the exhaust duct to record the exhaust air temperature. For calculating heat gain to the space, the temperature of the air approaching the appliance/hood combination is monitored by twelve aspirated RTD's mounted to four vertical posts in a semi circle around the appliance.

Pressure transducers are used to monitor airflow station pressures, room differential pressure, exhaust hood static pressure and natural gas pressure with an accuracy of 0.25% of full scale. The barometric pressure is measured with a transducer having an error of less than 0.1% of full scale.

Gas volume is measured with laboratory grade, positive displacement gas meters, which are modified to provide a pulse output to the data acquisition system. The calorific value of the natural gas is continuously measured to within 0.1% to monitor the amount of energy contained in each cubic foot of natural gas. The energy input from natural gas is then calculated from volume, calorific value, and temperature of the natural gas.

Standard utility watt-hour meters measure regulated 208V three phase electrical energy with pulse outputs to the data acquisition system. A watt-hour transducer monitors 120VAC single-phase energy input.

All measuring devices and instrumentation are periodically calibrated against standards of known accuracy. Using NIST traceable calibration standards, their respective manufacturers certify the calibration instruments according to a documented calibration schedule.

Precision and Bias

The statement of Precision and Bias in the *ASTM 1704-99 Standard Test Method for the Performance of Commercial Kitchen Ventilation Systems* states that the error in the capture and containment and heat gain to space values shall not exceed 20%. The airflow measurements in the laboratory comply with the referenced AMCA 210/ASHRAE 51 Standard. The measurement error for the second supply airflow rate is less than 2% and the measurement error on the primary supply airflow rate is less than 1%. The repeatability of capture and containment measurements at the CKV laboratory was investigated and the error was found to be below 14% with a typical error of about 7%. Circumstances that affect the capture and containment repeatability include situations that render the visualization system less effective such as dilution air that reduces the temperature difference between exhaust air and room air, and thermal plume temperatures near ambient conditions.