Commercial Kitchen Ventilation Performance Report

Electric Full-Size Convection Oven Under Canopy Hood

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As part our research project, we participated in an inter-laboratory test program conducted with American Gas Association Research to support development of the Standard Test Method for Performance of Commercial Kitchen Ventilation Systems which has been adopted as ASTM Standard F1704-96. We would like to thank Mr. Eliott Gordon of Halton Company, formerly CKV Program Manager with AGA Research, and Mr. Fuoad Parvin, Project Manager, AGA Research, for the opportunity to work with them in refining the Standard Test Method.

Mr. Don Fisher and Ms. Judy Nickel of Fisher Consultants and their research team at PG&E's Food Service Technology Center in San Ramon, California, have provided superior technical support throughout our investigations. We would like to thank our fellow researchers for teaching us what it takes to create large volumes of engineered french fries, hamburgers, and baked potatoes with high precision.

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EXECUTIVE SUMMARY

This report documents performance testing of an electric full-size convection oven positioned under an exhaust-only canopy hood. This set of tests is one of a series undertaken to provide electric utilities and the food service industry with data to promote minimum energy ventilation design by optimizing the design of commercial kitchen exhaust hoods and integrating exhaust requirements with space-conditioning design. The tests were conducted in accordance with ASTM F1704-96 Standard Test Method for Performance of Commercial Kitchen Ventilation Systems,[1] except as otherwise noted.

The performance tests included the determination of the minimum exhaust air flow rate to achieve full capture and containment of the effluent plume, as well as the net heat gain to the kitchen space under "idle" and "cooking" conditions. The appliance and hood test set-up consisted of an electric full-size convection oven positioned under a five-foot wide by four-foot deep exhaust only canopy hood.

The UL Listed flow rate for the tested exhaust hood is about 108% greater than required for the electric full-size convection oven under cooking test conditions. Since this hood is sold by the manufacturer as an off-the-shelf unit that may be used for gas or electric appliances, the UL Listed exhaust rate provides a safety margin that may be required for other appliances.

The building code capture and containment rate for this hood and appliance combination is clearly excessive. For the electric full-size convection oven, the idle capture and containment flow rate is 71% less and the cooking capture and containment flow rate is 69% less than the building code rate. Full capture and containment can be achieved with less exhaust in this case.

Electric Full-Size Convection Oven	Idle C & C	Cooking C & C	UL	Code
Capture & Containment (scfm)	575	625	1300	2000
Capture & Containment (scfm/linear ft)	115	125	260	400

Heat gain to the space was greater during cooking conditions than in idle conditions. For comparison, the ASHRAE heat gain figures were calculated to be 1.85 kBtu/h for an electric full-size convection oven using the data from Table 8 in Chapter 26, 1993 ASHRAE Handbook of Fundamentals. For the series of idle and cooking tests reported, the ASHRAE figure slightly understates heat gain at idle and significantly understates it for cooking.

Electric Full-Size Convection Oven	At Idle C & C	At Code Exhaust Rate
Heat Gain to Space During Idle Conditions (kBtu/h)	1.94	1.76

Electric Full-Size Convection Oven	At Cooking C & C
Heat Gain to Space During Cooking Conditions (kBtu/h)	6.44

Results of these tests are provided to publishers of building codes and design standards to improve the technical basis for cooking ventilation, occupancy ventilation, and HVAC related requirements and recommendations.

1

INTRODUCTION

The purpose of the reported research is to provide electric utilities and the commercial cooking industry with data to optimize the design of commercial kitchen exhaust hoods and to optimize interaction with heating, ventilating, and air-conditioning systems.

Results of the reported tests are provided to publishers of building codes and design standards to improve the public domain database relative to commercial cooking ventilation, including the American Society of Heating, Refrigeration, and Air-conditioning Engineers[2] and the publishers of the International Building Mechanical Code.[3] A desired outcome of the research is to develop optimized cooking ventilation strategies for various combinations of cooking appliance and exhaust hood styles, which may reduce new construction costs and operating costs for the restaurant owner and contribute to overall improvement of the environment.

The reported tests were performed in accordance with ASTM F1704-96 Standard Test Method for the Performance of Commercial Kitchen Ventilation Systems (CKV-STM). Performance of commercial kitchen hoods requires assessing the ability of the hood to capture and contain a thermal plume and/or cooking effluent and quantifying the heat gain to the kitchen space from the cooking appliances. Capture and containment is evaluated using visualization techniques. Direct measurement of heat gain to the kitchen space is very difficult and expensive to perform. Therefore the CKV-STM uses an indirect approach in which heat gain is calculated using an energy balance protocol. The heat from an appliance, in the idle or cooking mode, is transferred to the kitchen space primarily by radiation and secondarily by a combination of conduction and convection. The energy balance protocol is based on measurement of the energy added to and removed from the space over the test period while the appliance is operated in the idle or cooking mode.

This report contains results from testing an electric full-size convection oven under a five-foot wide by four-foot deep exhaust-only, wall-mounted canopy hood.

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EQUIPMENT TESTED

Tests were performed using a convection oven that utilizes full-size sheet pans. The oven compartment measures 20 inches high by 29 inches wide by 31 inches deep. The oven input power is rated at 12.1 kW, 208 V, 3Φ, 60 Hz.

The full-size convection oven was positioned under an exhaust-only canopy hood in accordance with ASTM F1496-93, Standard Test Method for the Performance of Convection Ovens. A cross-sectional view of the test setup is shown in Figure 1. Set-back from the front edge of the hood was six inches. The hood is UL Listed at 1300 cfm for cooking operation, and is five-feet wide by four-feet deep by two-feet high with three 19-1/2- by 19-1/2-inch standard baffle filters positioned in the upper rear of the hood in front of a 17- by 11-inch duct opening.

The oven operating temperature was set to 350°F and verified using calibrated thermocouples.

The capture and containment flow rates for idle and cooking modes were determined. An additional two test points were set using building mechanical code exhaust requirements of 100 cfm per square foot of hood (2000 cfm total) and ASTM cooking performance test flow rate for full-size convection ovens[4] of 300 cfm per linear foot of hood (1500 cfm total). These points were selected to provide additional heat gain data at industry-accepted flow rates and to provide sufficient test points as specified in the CKV-STM to generate an acceptable heat gain curve.

Each test condition was run a minimum of three times in a consecutive series of tests to attain statistical certainty prescribed in the CKV-STM. During idle testing, four heat gain tests were run at four lower flow rates below idle capture and containment to aid in characterizing the idle heat gain curve. The majority of the test runs were generated by going from the highest required cfm to the lowest.

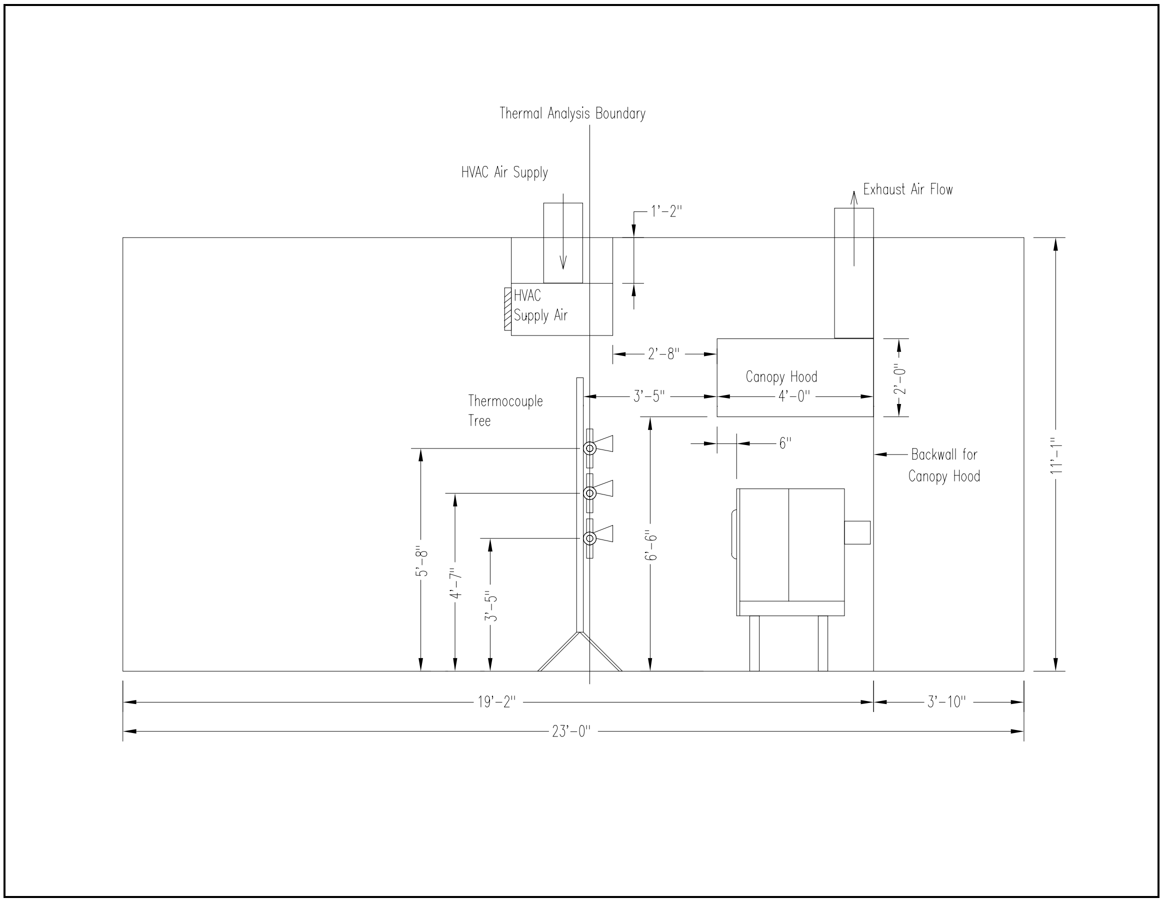

Figure 1
Cross Section View of Appliance and Hood Configuration

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TEST RESULTS

The figures and tables in this section show a summary of the test results for an electric full-size convection oven under a canopy hood during idle and cooking conditions. Figure 2 shows the appliance energy input, energy exhausted, and heat gain to the kitchen space during idle conditions. The graph's primary axis shows energy rate in customary heat transfer units (thousands of Btu per hour). A secondary axis shows the equivalent electric power units for energy exhausted and heat gain to space. Appliance energy input increased slightly as the exhaust flow rate increased. At idle, appliance energy consumption was 16% of rated input.

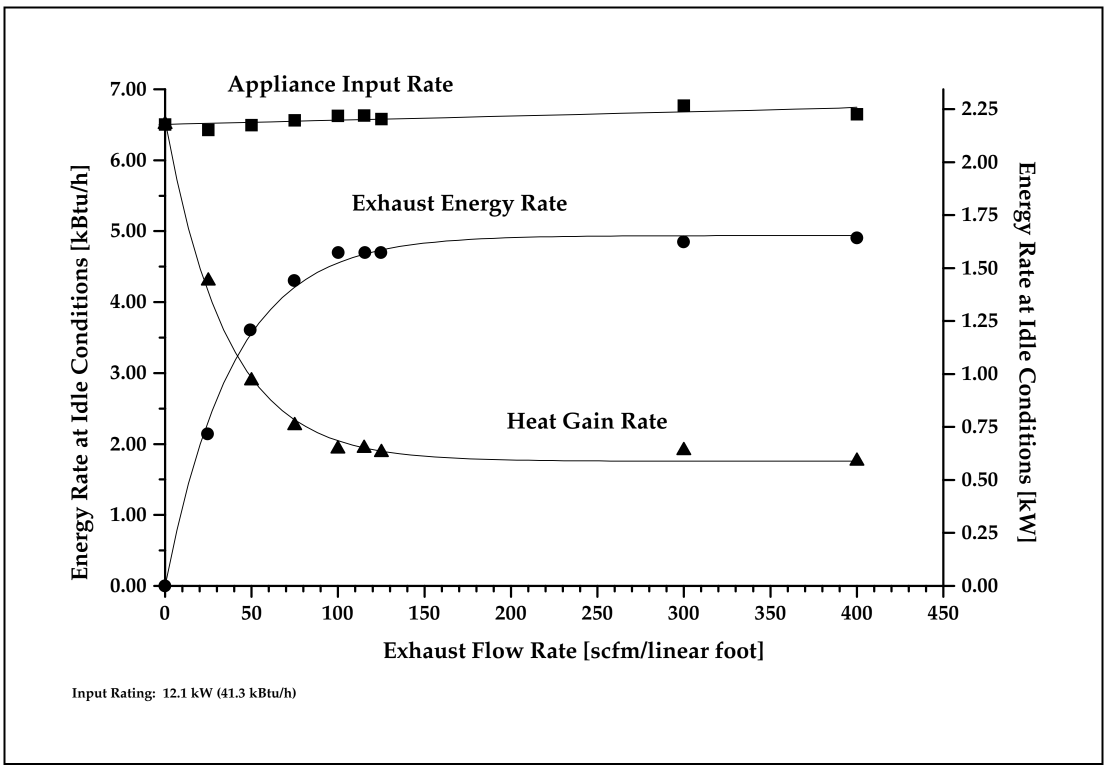

Figure 2
Appliance Energy Input, Energy Exhausted, and Heat Gain to Space for
Electric Full-Size Convection Oven under a Five-Foot Exhaust-Only Hood During Idle Conditions

Heat gain to space during idle conditions remained relatively constant as ventilation rate decreased from code rate to idle capture and containment rate.

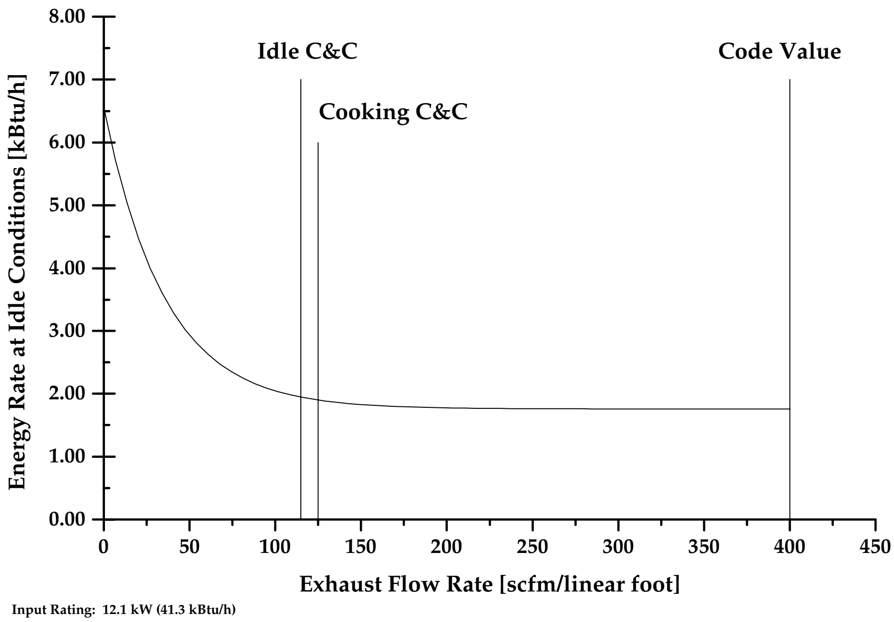

Figure 3
Heat Gain to Space at Idle Conditions for Electric Full-Size Convection Oven at Idle, Cooking, and Mechanical Code Capture and Containment Exhaust Flow Rates

Figures 4 and 5 illustrate how capture and containment for the electric convection oven under the canopy hood was determined using schlieren flow visualization. The thermal plume rising from the appliance is not seen by the naked eye, but appears as cloud-like swirls when using the schlieren flow visualization technique. Spillage is determined by looking for hot air escaping along the lower lip of the hood, typically at the corners of the hood. The threshold of capture and containment is the point where there is no spillage of the thermal plume from the hood.

Figure 4 shows full capture and containment at 200 scfm/linft of hood. The threshold of capure and containment for idle conditions was determined to be 115 scfm/linft and for cooking conditions was determined to be 125 scfm/linft. Figure 5 shows spillage of thermal plume at 60 scfm/linft

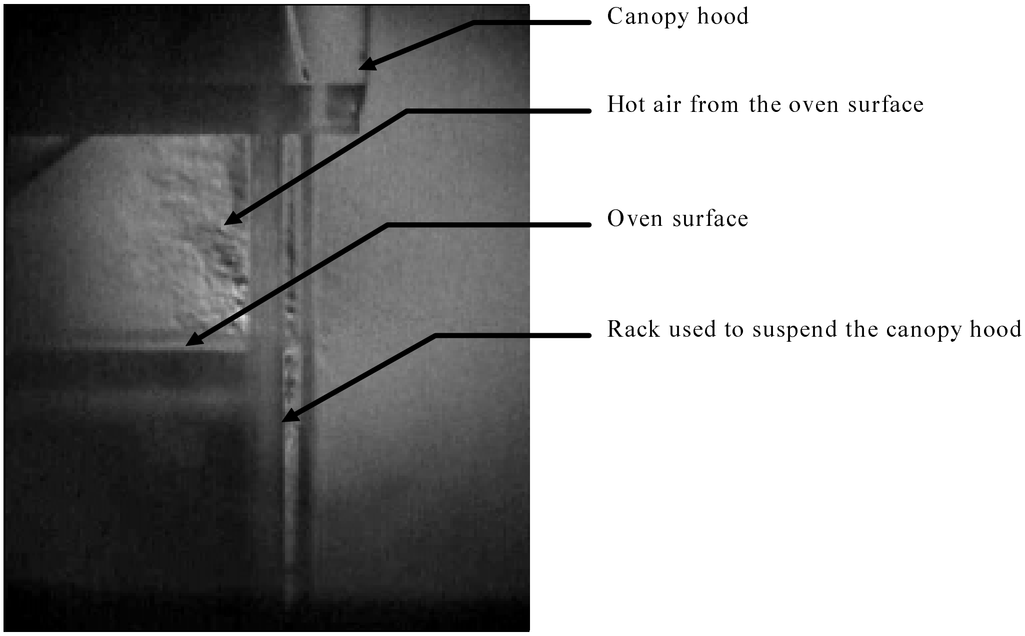

Figure 4
Schlieren Photograph of the Electric Oven During Capture and Containment at 200 Scfm/Linear-Foot of Hood

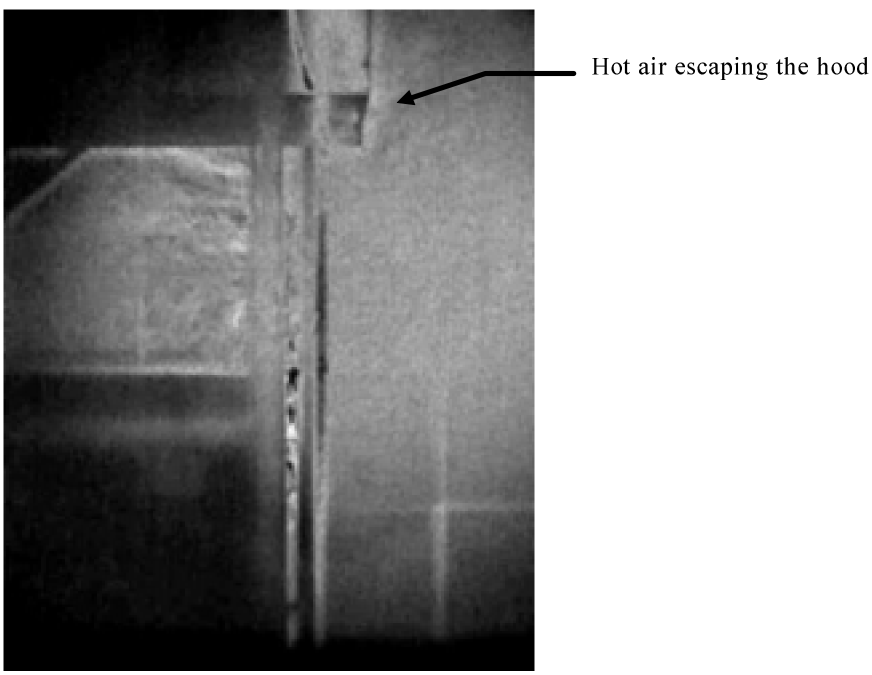

Figure 5
Schlieren Photograph of the Electric Oven During Spillage at 60 Scfm/Linear-Foot of Hood

During cooking, the average energy distribution was as follows: 28.5 kBtu/h (8.35 kW) for appliance input, 5.24 kBtu/h (1.54 kW) for energy exhausted, 16.8 kBtu/h (4.92 kW) for energy to food, and 6.44 kBtu/h (1.98 kW) for heat gain to the kitchen space. At cooking, appliance energy consumption was 69% of rated input.

The increased heat gain to space during cooking versus idling is due to the longer on-time of the elements. When cooking, the energy input is about 4.3 times greater than during idle. The longer element on-time allows more heat to be transferred through the oven walls. Conductive heat transfer through the oven walls is aided by the high-velocity convection fan.

Table 1 shows a summary of results for each test performed at idle conditions. Three tests were performed at each exhaust flow rate above idle capture and containment. Four additional tests were conducted below capture and containment to improve the heat gain to space curve fit. Table 2 shows a summary of the uncertainty calculations for tests at or above idle capture and containment. The uncertainty for all test series was below the 15% limit required by ASTM F1704-96.

Table 1
Summary of Appliance, Net Exhaust, and Heat Gain Energy at Idle Conditions by Exhaust Flow Rate

SCFM	Test Numbers	SCFM/LINFT	Energy Appliance kBtu/h	Energy Exhaust-Net kBtu/h	Energy Heat Gain kBtu/h	Make-Up Air Temp °F
2000	ACLB35K5	400	6.65	4.91	1.74	76.1
2000	ACLB36K5	400	6.63	4.89	1.74	75.9
2000	ACLB37K5	400	6.67	4.88	1.79	76.1
1500	ACLB21K5	300	6.75	4.84	1.91	76.1
1500	ACLB22K5	300	6.84	4.86	1.98	76.3
1500	ACLB23K5	300	6.70	4.85	1.85	76.2
625	ACLB24K5	125	6.61	4.65	1.96	76.1
625	ACLB25K5	125	6.60	4.73	1.87	75.5
625	ACLB26K5	125	6.54	4.74	1.80	75.4
575	ACLB27K5	115	6.58	4.59	1.99	76.1
575	ACLB28K5	115	6.60	4.75	1.85	75.5
575	ACLB34K5	115	6.69	4.70	1.99	75.4
500	ACLB29K5	100	6.62	4.69	1.93	76.7
375	ACLB30K5	75	6.56	4.30	2.26	76.8
250	ACLB31K5	50	6.50	3.61	2.89	76.7
125	ACLB16K5	25	6.43	2.13	4.30	76.1

Table 2
Summary of Heat Gain at Idle Conditions Uncertainty Analysis

SCFM/Lin Ft	Average Heat Gain kBtu/h	Sdsample kBtu/h	% Uncertainty
400	1.76	0.025	3.56
300	1.91	0.065	8.48
125	1.88	0.082	10.83
115	1.94	0.084	10.74

Table 3 shows a summary of results for each test performed at cooking conditions. A minimum of three tests were performed at each exhaust flow rate. Table 4 shows a summary of the uncertainty calculations.

Table 3
Summary of Appliance, Net Exhaust, and Heat Gain Energy at Cooking Conditions by Exhaust Flow Rate

SCFM	Test Numbers	SCFM/LINFT	Energy Appliancek Btu/h	Energy Exhaust-NET	Energy To Food kBtu/h	Energy Heat Gain kBtu/h	Make-Up Air Temp °F
1500	BLCB02K5-2	300	28.6	5.58	16.9	6.12	76.9
1500	BLCB02K5-3	300	28.4	5.03	16.5	6.84	76.7
1500	BLCB02K5-4	300	28.5	5.11	17.0	6.37	76.7

Table 4
Summary of Heat Gain at Cooking Condition Uncertainty Analysis

SCFM/Lin Ft	Average Heat Gain kBtu/h	Sdsample kBtu/h	% Uncertainty
300	6.44	0.366	14.1

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CONCLUSIONS

General Observations

A significant contributor to kitchen heat gain is radiation from the appliance and hood surfaces. The temperatures of kitchen room surfaces gradually increase which in turn heat up the air in the room. This transfer mechanism adds heat to all objects in the room and is offset slightly by convective cooling of room objects at higher air flow rates.

The rate of heat gain to space changes with exhaust air flow by the following mechanisms:

- When reducing air flow rates below full capture and containment, heat gain to the room increases by convection as well as radiation.
- The heat gain to space under idle conditions is relatively constant at all air flow rates above capture and containment. Other tested appliances, such as griddles, have shown slight decreases in heat gain to space under idle conditions as air flow rate increases.
- Under cooking conditions, heat gain to space is significantly higher compared to idle conditions due to the increased energy consumption. During cooking, a large fraction of the energy consumed by the appliance is used to vaporize water in the food and to raise the temperature of the food as it is cooked. However, heat gain to space is about three times greater than during idle, and energy exhausted is slightly greater than during idle.

Comparison of Test Data with Building Codes and ASHRAE Data

Cooking capture and containment was achieved significantly below the UL Listed rate and substantially below the building code rate.

The UL Listed exhaust flow rate for the tested hood is about 108% greater than required for the electric full-size convection oven under cooking test conditions. Since this hood is sold by the manufacturer as an off-the-shelf unit that may be used for gas or electric appliances, the UL Listed exhaust rate provides a safety margin that may be required for other appliances.

The building code capture and containment rate for this hood and appliance combination is clearly excessive. For the electric full-size convection oven, idle capture and containment flow rate is 71% less and the cooking capture and containment flow rate is 69% less than building code rate. Full capture and containment can be achieved with less exhaust in this case. Table 5 shows the minimum capture and containment exhaust volumetric flow rates measured under idle and cooking, as well as the UL Listed and building code rates.

Table 5
Capture and Containment Exhaust Volumetric Flow Rates Using Laboratory Measured Data at Idle and Cooking, Compared to the UL Listed Rate and the Building Code Rate

Electric Full-Size Convection Oven	Idle C & C	Cooking C & C	UL	Code
Capture & Containment (scfm)	575	625	1300	2000
Capture & Containment (scfm/linear ft)	115	125	260	400

Heat gain to the space was greater during cooking conditions than at idle conditions. The ASHRAE heat gain figures were calculated to be 1.85 kBtu/h for an electric full-size convection oven at idle condition using the data from Table 8 in Chapter 26, 1993 ASHRAE Handbook of Fundamentals, compared to 1.94 kBtu/h at the idle capture and containment exhaust flow rate, and 6.44 kBtu/h at the cooking capture and containment exhaust flow rate. For the series of idle and cooking tests reported, the ASHRAE figure slightly understates heat gain at idle and significantly understates it for cooking.

Table 6
Heat Gain to Space During Idle Conditions Calculated Using Laboratory Measured Data at Idle Capture & Containment and Building Code Exhaust Ventilation Rates

Electric Full-Size Convection Oven	At Idle C & C	At Code Exhaust Rate
Heat Gain to Space During Idle Conditions (kBtu/h)	1.94	1.76

Table 7
Heat Gain to Space During Cooking Conditions Calculated Using Laboratory Measured Data at Cooking Capture & Containment and Building Code Exhaust Ventilation Rates

Electric Full-Size Convection Oven	At Cooking C & C
Heat Gain to Space During Cooking Conditions (kBtu/h)	6.44

APPENDIX A - THEORY AND ANALYSIS

The two principal results of the Standard Test Method for the Performance of Commercial Kitchen Ventilation Systems (CKV-STM) are:

(1) capture and containment volumetric air flow rates under idle and cooking conditions, and

(2) heat gain to space under a range of volumetric air flow rates.

The CKV-STM summarizes its test method as follows in Section 4:

> 4.1 This test method is used to determine the performance of commercial kitchen ventilation systems. Such systems include one or more exhaust hoods, one or more cooking appliances under the hood(s), other appliances and miscellaneous heat sources not under the hood(s), and a means of providing makeup air, which may include makeup through the hood as well as the HVAC system. Ventilation system performance includes the evaluation of capture and containment of products from cooking operations and the effect of heat gained by the space which impacts human comfort and equipment operation, over exhaust flow rates ranging from minimum capture up to maximum capacity or code value.
>
> 4.2 The test method provides a technique for assessing capture and containment quantitatively by means of an overall balance of energy consumed by the test appliance(s) and the sum of energy exhausted, energy gain to test space, and energy transferred to food, if any.
>
> 4.3 The exhaust hood under test is connected to an exhaust duct and fan, and mounted in an air-tight room The exhaust fan is controlled by an variable speed drive to provide operation over a wide range of exhaust rates. A complementary makeup air fan is controlled to balance the exhaust rate, thereby maintaining a negligible static pressure difference between the inside and outside of the test room.
>
> 4.4 Because of potential problems with measurement in the hot, possibly grease-laden exhaust air stream, exhaust air flow rate is determined by measuring the makeup air flow rate on the supply side. Design of the airtight test facility ensures

that the supply rate equals the exhaust rate since air leakage outside the system boundary (i.e. all components between supply and exhaust blowers making up the system) is negligible.

4.5 The performance of the hood, relating to capture and containment, is measured through the energy balance measurements and calculations, determined over a range of hood exhaust rates. The plotted curve of energy gain to the test space versus exhaust rate represents kitchen ventilation system performance, in terms of heat gain/cooling load associated with the tested appliance(s), and capture and containment under idle conditions.

4.6 In the simplest case, under idle mode, energy exhausted from the test system is measured and subtracted from the energy into the appliance(s) under the hood; the remainder is energy gain to the test space. Energy gain is then determined over a wide range of exhaust flow rates. In cooking mode, energy to food must also be subtracted from the appliance energy input to calculate heat gain.

There are four significant measurements that must be made under the CKV-STM: supply air flow rate, supply air temperature, exhaust air temperature, and appliance input energy. The air flow rate is required for capture and containment tests, and all four measurements are required for the heat gain tests.

Capture and Containment Testing

The phrase “hood capture and containment” is defined in the CKV-STM 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 from the area under the hood, while containment refers to these products staying in the hood reservoir and not spilling out of the hood into the space adjacent to the hood.

The phrase “minimum capture and containment” is defined as:

> the conditions of hood operation in which minimum exhaust flow rates are 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.

The minimum exhaust air flow rate required for complete capture and containment of the thermal plume and/or cooking effluent is determined prior to running the heat gain tests for a given hood/appliance combination. Two minimum capture and containment air flow rates are established—one with the appliance idling and one with the appliance cooking food under full-load conditions.

Air flow visualization is enhanced by using intrusive seeding and non-intrusive optical techniques. Smoke generators (theater-type fog generator) or neutrally-buoyant bubble generators are examples of intrusive seeding techniques to enhance visibility of the thermal plume rising from the heated cooking appliance. This is particularly useful at idle conditions and with appliances that produce little visible effluent.

Optical techniques, such as high-intensity light focused in a plane parallel to a face of the hood, or a schlieren-principle flow visualization system may be used. A schlieren system is particularly useful because video images may be recorded on tape for future use. In many cases, schlieren visualization may be used without intrusive methods such as smoke or bubbles.

During the test, the exhaust flow rate is reduced until spillage of the thermal plume and/or effluent is observed. The exhaust flow rate is then gradually increased in fine increments until full capture and containment is achieved. The air flow rate at this condition is referred to as the threshold exhaust air flow rate for complete capture and containment (C&C).

Heat Gain to Space Testing

Heat gain to the space is determined indirectly by monitoring make-up air volumetric flow rate, the temperature of make-up air moving toward the operating appliance/hood combination, the temperature of the air moving through the exhaust duct, and the energy input into the appliance.

The energy balance is:

$$\sum E_{in} = \sum E_{out} \tag{1}$$

or

$$E_{appliance} + E_{make\ up\ air} = E_{exhaust} + E_{heat\ gain} + E_{food} \tag{2}$$

for the cooking case

$$E_{heat\ gain} = E_{appliance} + E_{make\ up\ air} - E_{exhaust} - E_{food} \tag{3}$$

and for the idle case

$$E_{heat\ gain} = E_{appliance} + E_{make\ up\ air} - E_{exhaust} \tag{4}$$

However, if the energy of the make up air is calculated at a plane three feet in front of the hood by a set of aspirated temperature sensors mounted on stands (also known as "thermometer trees", "T-trees" or simply "trees"), the equation for the idle case reduces to:

$$E_{\text{heat gain}} = E_{\text{appliance}} + E_{\text{tree}} - E_{\text{exhaust}} \quad (5)$$

or

$$E_{\text{heat gain}} = E_{\text{appliance}} - m\, c_p\, [T_{\text{exhaust}} - T_{\text{tree}}] \quad (6)$$

or

$$E_{\text{heat gain}} = E_{\text{appliance}} - 1.08\, Q\, [T_{\text{exhaust}} - T_{\text{tree}}] \quad (7)$$

where m = mass flow rate of total make-up air (lb_a/h),

c_p = specific heat of air stream supplied to hood (0.244 Btu/lb_a °F), and

Q = volumetric flow rate supplied to hood (cfm).

APPENDIX B - LABORATORY

The laboratory test area consists of a room, approximately 38 feet long by 24 feet wide by 11 feet high, that is completely contained within a large manufacturing facility and warehouse. The manufacturing facility and warehouse is minimally heated in winter and is not cooled in summer. The lab supply air is cooled by a 17-ton chilled water air-conditioning system and is heated with a 20 kW thermostatically controlled electric duct heater. The air temperature in the laboratory is maintained at 75 - 78°F during testing.

Doors are located in the east and west walls of the laboratory. The east wall door is permanently sealed shut; the door in the west wall is used to enter and exit the laboratory. When closed that door seals air-tight. An AMCA certified air measurement station with a three-nozzle inlet chamber is located on the laboratory roof at the approximate centerline of the roof, running from west to east. Three roof penetration curbs, located to the south of the air measurement station, are available for test set-ups. Three additional curbs are located to the north of the air measurement station. Two of these are available for test set-ups, and the third has a safety water seal system installed over it to vent the laboratory in the event of a positive or negative air pressure build up within the laboratory. Only one test curb site can be used at a time, with the others sealed air tight. Two exhaust fans are located on the lab roof, one on each side of the supply duct. The speeds of the supply and exhaust fans are regulated and monitored on digital read-outs inside the laboratory.

By opening the air measurement station nozzles singly or in combination, the air flow into the laboratory can be varied from 200 cfm to 2100 cfm. The AMCA air flow measurement station conforms to the requirements of AMCA Standard 210.

The exhaust fan speed is set to maintain a pressure differential of ±0.002 inches water column between the laboratory and outside ambient when the laboratory is sealed air tight. The exhaust air flow is not directly measured due to potential contamination from cooking and combustion effluents. Since the supply air flow into the laboratory is accurately determined and the laboratory is airtight, the mass flow rate of exhausted air is equal to the mass flow rate of supplied air as long as the pressure differential is zero.

The maximum air flow rate that can be achieved, with all nozzles open, is dependent upon ambient atmospheric conditions outside the laboratory. A computer controlled data acquisition and process control system monitors pressure drop across the nozzles in the flow chamber, differential pressure between the laboratory and ambient, barometric pressure, air temperatures from up to 40 RTD sensors, dew point, energy input to tested appliances through electric Watt-hour meters, natural gas consumption, natural gas heating capacity, supply and exhaust fan speeds and several other parameters. This system also calculates the air flow through the laboratory continuously.

All capture and containment determinations are made with the exhaust fan under manual control. The computer system automatically adjusts the supply fan speed to achieve zero pressure differential between the laboratory and ambient. For heat gain determinations, the air flow is automatically set by the computer system according to a programmable test schedule along with test duration.

Computer Software, and Hardware

The facility uses three computers to acquire, reduce and analyze the data. Two Pentium based PCs are located in an office and are used for image processing for capturing and containment video pictures, data analysis, data presentation, word processing and administration. A 486/66 based PC handles data acquisition and process control tasks. It is located inside the laboratory and is equipped with a GPIB interface, an A/D and D/A converter board and an event counter board. The RTD temperature sensors are measured through a GPIB bus-controlled Keithley Instruments DMM2002 in combination with a Scanner 7001. The scanner is equipped with two 7011 scanner cards and is set up for 4-wire resistance measurement to achieve best accuracy with RTD sensors. All other analog input signals and analog outputs for fan control are done through a Keithley Metrabyte data acquisition board with channel multiplexer. The energy input transducers, including Watt-hour meters and positive displacement volume natural gas meters, are connected through signal conditioning electronics to a Keithley Metrabyte event counter board. An Architectural Energy Corporation MicroDataLogger® is used for comparative data acquisition and analysis.

All three computers are running the Windows95 operating system. The process control and data acquisition software was custom developed for this application in Visual Basic 4.0. Some of the hardware functions were provided through Keithley Metrabyte and Capital Equipment Corporation (CEC) as Windows Dynamic Link Libraries (DLL). Most of the data analysis is done with Microcal Origin, a scientific data analysis program with powerful graphing and curve fitting functions. Origin reads data files from the laboratory control computer directly through the network for instant evaluation.

Instrumentation

Differential pressures are measured on Validyne model PT132 low pressure gages having ranges up to 0.1 or 5 inches water column. These instruments are accurate to within 0.25% full scale. The barometric pressure is measured with a Setra systems Model 270 pressure transducer. The accuracy of that transducer is better than ±1mbar, that corresponds to an error of less than 0.125%.

Electric power input is measured with standard utility Watt-hour meters with pulse outputs for 208V 3phase supply. Energy input from 120VAC single phase is monitored with an Ohio Semitronics Watt-hour transducer. Energy input from natural gas is calculated from volumetric consumption as measured with gas positive-displacement meters with pulse outputs and the gas heating-value as measured with a natural gas calorimeter.

Temperatures are measured with RTD sensors located as needed to monitor a given test. Twelve aspirated RTDs are mounted to two vertical masts, located 2 to 4 feet in front of the appliances under test. Those RTDs record the temperature of the air approaching the appliance / hood combination. These RTD assemblies are referred to as "thermometer trees", "T-trees", or just "trees". An array of 12 RTDs, consisting of four short pieces of cut open steel pipe with each piece holding 3 RTDs, is placed in the exhaust duct to record the exhaust air temperature. The pieces of steel pipe are installed perpendicular to each other in the duct such that the RTDs are arranged in an equal-area concentric layout.

The focusing schlieren system at the CKV lab consists of a source grid made of special reflective material to create a uniform pattern of parallel light sources, shaped as dots on a black background, at one end of the lab. This source grid is illuminated through a halogen light source. On the opposite side of the lab an optical system projects the source grid and objects between source grid and optics onto an image screen. A photographically created negative image of the source grid, called a cut-off grid, is located right in front of that image screen. As long as the refractive index of the air between source grid and cut off grid equals one constant value the cut off grid eliminates all the light coming from the source grid and the image on the screen is dark. As soon as the refractive index of the air between source grid and cut off grid changes the image on the screen lightens up because the light rays from the source grid do not hit exactly the black areas on the cut off grid. This effect is called schlieren effect. It can also be observed on hot days as flickering of air over hot pavement. The system at the CKV lab is sensitive enough to detect the warm air coming off a person's body. An S-VHS video camera is scanning the image on the internal image screen of the schlieren system and transmitting the signal to a TV monitor and a S-VHS VCR.

Additional flow visualization can be done with a Rosco Fog Machine, Model 1500, that has a maximum smoke generation rate of 1500 cfm. A neutrally buoyant bubble generator Model 33 manufactured by Sage Action, Inc. is also available for airflow visualization.

APPENDIX C: TEST METHODOLOGY

All measuring devices and instrumentation are periodically calibrated against standards of known accuracy. The calibration instruments are certified by their respective manufacturers using NIST traceable calibration standards.

Pre-Test Operations

The Validyne pressure gages are periodically calibrated using a hook gage that is accurate to within ±0.001 inches of water column. The RTDs together with the Keithley Instruments temperature measurement system have an absolute accuracy of better than ±0.1°F. Over a period of 24 hours the accuracy of this system is better than ±0.005°F. In the described test setup this second accuracy value is the most important number because the system is calibrated through re-calibration tests every night. If the T-trees indicate the necessity of better air mixing within the laboratory a set of air mixer stacks can be set up.

Test Operations

Before the first test of the day is performed, the room air flow is set to the required level, the appliance powered on and allowed to come to cooking temperature. After the cooking temperature is reached, the appliance cycles for a minimum time of one hour. The laboratory is then operated for another hour, minimum, to ensure stabilization of the laboratory, hood, ductwork, and equipment.

For subsequent tests at different air flows, the laboratory is stabilized for a minimum of one-half hour prior to the test actually being run. For a given day, the test sequence starts with the highest exhaust volumetric flow rate and proceeds to lower air flow rates.

Each idle test is operated for a minimum of two hours for thermostatically controlled appliances to assure that energy input to the appliance has stabilized for the selected exhaust flow rate. Cooking tests also require 20 minutes after a stabilization period.

The data acquisition computer writes one complete set of data every 4 seconds to a data file. Data is analyzed statistically and is accepted and used only when it has an uncertainty value less than 15% within 95% confidence limits. When a problem is discovered or suspected with a test or series of tests the results of those tests are disregarded, the problem cause is corrected and the tests are repeated. Occasionally results are accepted that are outside the 15% uncertainty limit. This is usually due to uncertainty associated with calculating energy to food during cooking tests.

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[1] *ASTM* F1704-96 *Standard Test Method for Performance of Commercial Kitchen Ventilation Systems.* American Society for Testing and Materials, West Conshohocken, PA. (1996).

[2] American Society of Heating, Refrigeration, and Air-conditioning Engineers, 1791 Tullie Circle NE, Atlanta, GA 30329-2305.

[3] International Building Mechanical Code, International Code Council, Inc. The Council is made up of the Building Officials and Code Administrators International, Inc., the International Conference of Building Officials, Inc., and the Southern Building Code Congress International, Inc.

[4] *ASTM F1496-93, Standard Test Method for the Performance of Convection Ovens.* American Society for Testing and Materials, West Conshohocken, PA. (1993).