Capture Efficiency and Indoor Thermal Environment inside Commercial Kitchen using Low Radiation Cooking Equipment with Concentrated Exhaust

S. Takano, K. Sagara, T. Yamanaka, and H. Kotani
Osaka University

S. Chihara
West Japan Railway Company.

ABSTRACT

In commercial kitchen, a large amount of heat and moisture as the effluence need to be removed. Therefore, a large ventilation rate is needed and energy consumption can be large in commercial kitchen. To improve kitchen condition, supply efficient oxygen and save the energy, low radiation cooking equipments with concentrated exhaust were developed. This paper summarizes laboratory investigation into the effect of low radiation cooking equipment with concentrated exhaust on commercial kitchen condition. We monitored indoor thermal environment and capture efficiency under operation of these equipments this time. The appliances used for this investigation are gas range, gas fryer, gas kettle.

1.INTRODUCTION

In a commercial kitchen, a large amount of heat and moisture as the effluence need to be removed. In addition, gas cooking equipments involve combustion, so kitchen in which those equipments is put needs enough oxygen. Therefore, a large ventilation rate is needed and energy consumption can be large in commercial kitchen.

A number of studies have examined the complete capture and containment (C&C) exhaust rate requirements. ASTM Standard F 1704-99, Performance of Commercial Kitchen Ventilation System (ASTM 1999a) incorporates procedures to determine C&C exhaust rates for kitchen exhaust hoods and heat gain to space from hood/appliance systems. The heat gain curve identified the minimum C&C exhaust flow rate for a hood/appliance system at the "knee" of the curve. Applying ASTM 1704, the heat gain and C&C exhaust values were determined for variety of single appliances under canopy hood (Knappmiller and Schrock 1997).

A schlieren flow visualization technique was developed so as to research the electric industry-sponsored program. A schlieren visualization system was incorporated into the Commercial Kitchen Ventilation (CKV) lab for C&C testing, complemented by the CKV lab's heat gain testing capabilities (Smith et al). The C&C and heat gain data from the electric industry-sponsored project were made public(EPRI 1997) and used with additional laboratory data to improve ASHRAE documentation for generic hood C&C exhaust rates(Swierczyna et al. 1997) and values for appliance heat gain to space(Fisher 1998; ASHRAE 2001).

ASHRAE Research Project RP-1202 (Swierczyna et al. 2005) quantified the effect of the position and/or combination of appliances under an exhaust hood on the minimum C&C exhaust rate. Effects of side panels, front overhang, and rear seal were also investigated. The result is anticipated to help designers optimize the performance of CKV systems. In Japan, the capture efficiency of standard exhaust hood for exhaust gas and contaminant generated by cooking above the commercial cooking stoves and fryers were measured on two kinds of heat sources of natural gas and electromagnetic heat (Yamanaka et al. 2000). In addition, the influence of moving person is measured (Momose et al. 2000). Capture efficiency under actual room condition is different from that described above. The measurement method of capture efficiency under actual room condition is developed (Kurabuchi et al. 2007)

In those days, low radiation cooking equipments with concentrated exhaust were developed to improve kitchen condition, supply efficient oxygen and save the energy. Outline of this equipment is shown in Figure 1. These equipments have two technologies. First, surface temperature of the equipments is lower than that of normal equipments. This reduces radiative heat toward the worker and the room. Second, generated CO_2 is exhausted effectively by using concentrated exhaust tube. This reduces the diffusion of effluences to the room(containing heat of combustion and CO_2). Exhaust flow rate requirements can become smaller by these technologies. However there are few studies on low radiation cooking equipment with concentrated exhaust as mentioned above. Therefore the purpose of this study is to prove the energy saving performance of low radiation cooking equipment with concentrated exhaust and build up design guideline of ventilation system under operation of these equipments.

2. OUTLINE OF EXPERIMENT

2.1 Experimental Room and Cooking Equipment

A plan and cross-section of Experimental room are shown in Figure 2. Two experimental rooms of 4.5×3.5×2.5 m are prepared side by side. One is for low radiation equipments operation, the other is for conventional equipments operation. In each laboratory, a kettle, a range and a fryer are put from the left. The specific of cooking equipment is shown in Table 1. Kettles and ranges are maintained continuous boiling the water by maximum gas input. Fryers are maintained continuous heating the water instead of using oil to keep the maximum gas input. The water temperature in a fryer is maintained 90℃ by supplying and draining water.

Experimental room is located in large

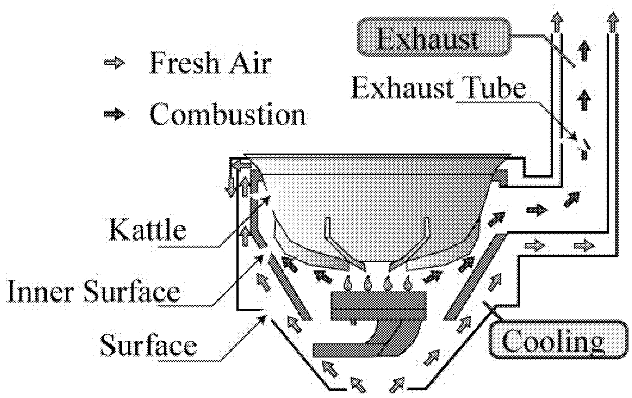
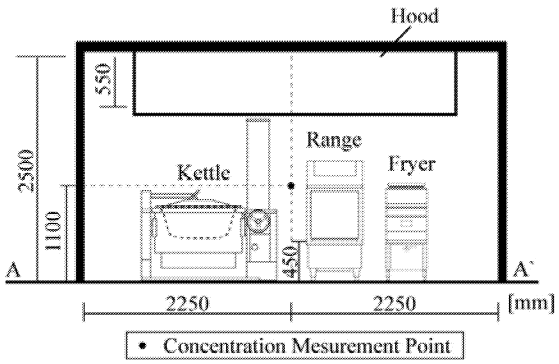


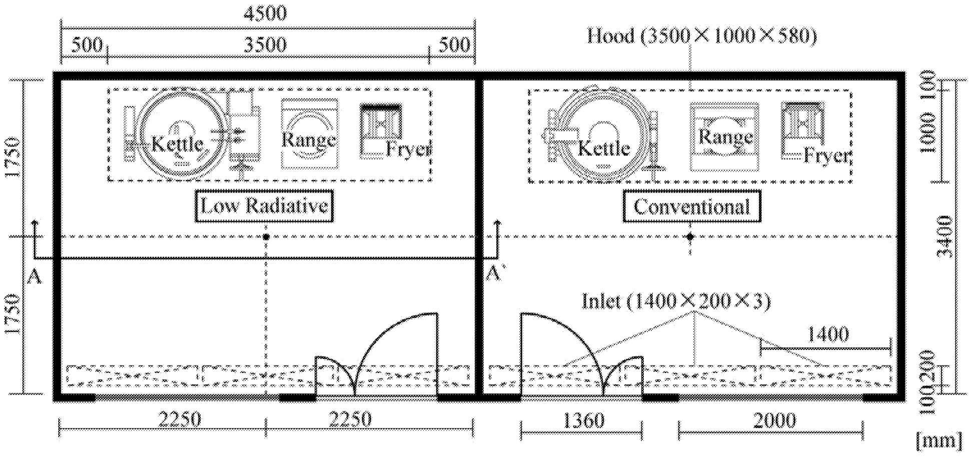
Figure 1 Outline of Low Radiation Cooking Equipments

Table 1 Cooking Equipments

	Low Radiative			Conventional		
	Kettle	Range	Fryer	Kettle	Range	Fryer
Input [kW]	34.9	20.9	8.37	37.2	17.4	10.5
Dimension [mm]	B1465 ×L1004 ×H1940	B600 ×L750 ×H450	B450 ×L600 ×H850	B750 ×L948 ×H1765	B750 ×L750 ×H450	B450 ×L600 ×H850



(a) Cross-Section



(b) Plan

Figure 2 Experimental Room

experimental space, so “Outdoor air” means the air in experimental space. Air-conditioned outdoor air is supplied by three ceiling inlets. Effluence is exhaust by only the hood.

2.2 Measurement Procedure of Capture Efficiency

CO_2 concentration in the room and the exhaust duct are measured all times during measurement. At the first, we bring the water to boil on each equipment. Secondly, we stop heating to go back indoor concentration(C_B) to supply concentration (C_S). At the third, we start heating again, and wait until indoor and duct concentrations(C_E) become steady state. Finally, we stop heating again and wait until indoor concentrations become supply concentration. It is thought that duct concentration in steady state is approximately equal to that in 100% capture efficiency. By the derivation, the capture efficiency η is calculated as follows.

$$\eta = \frac{C_E - C_B}{M} \cdot V = \frac{C_E - C_B}{C_E - C_S} \qquad (1)$$

where

C_E: ten minutes mean duct concentration before stopping gas supply

C_B: ten minutes mean indoor concentration before stopping gas supply

C_S: ten minutes mean supply air concentration before stopping gas supply

M: CO_2 generation rate

V: Exhaust flow rate

CO_2 concentration change in measurement is shown in Figure 3. In this measurement, mean indoor concentration can not be presumed. This is because duct concentration decreased smoothly after stopping gas supply. In fact, indoor concentration around measurement point have -5-+8% horizontal distribution and -3-+30% vertical distribution on low radiation kitchen (face velocity 0.3m/s). The capture efficiency in this time is that in the case indoor concentration is constant even though exhaust flow rate and equipment change. This experiment carried out in five exhaust flow rate, that is 1190 (1200) m^3/h, 1790 (1800) m^3/h, 2390 (2400) m^3/h, 3300 m^3/h, 4400 m^3/h. These flow rates correspond to 20KQ,30KQ, 40KQ, face velocity 0.3m/s and face velocity 0.4m/s. Here, K means theoretical combustion gas flow rate per heating power $m^3/h \cdot kW$ and Q means heating power of gas kW. Experimental condition is shown in Table 2.

2.3 Indoor Thermal Environment

First, we open all covers after we bring the water to boil at each equipment. We decide that the state which wall surface temperature is steady is steady state. We measure temperature and relative humidity at the time. The measurement points are 18 points of horizontal direction and 5 points of vertical direction, that is 90 points. We measure globe temperature in the front of each equipment and the middle of room in order to check effect of radiation. The measurement points are shown in Figure 4, and the measurement items are shown in Table 2.The supply air temperature is set up at constant temperatureof 18 deg. Exhaust flow rate is set up five conditions which is the same of previous experiment. Experimental condition is shown in Table 4.

3. RESULTS AND DISCUSSIONS

3.1 Capture Efficiency

Relationship between exhaust flow rate and capture efficiency is shown in Figure 5. For the reason mentioned above, it wants to be careful that experimental value is reference value. In low radiation kitchen, capture efficiency improve significantly. For example, capture efficiency is about 80 % even though the flowrate is small as 1190 m^3/h. This is because

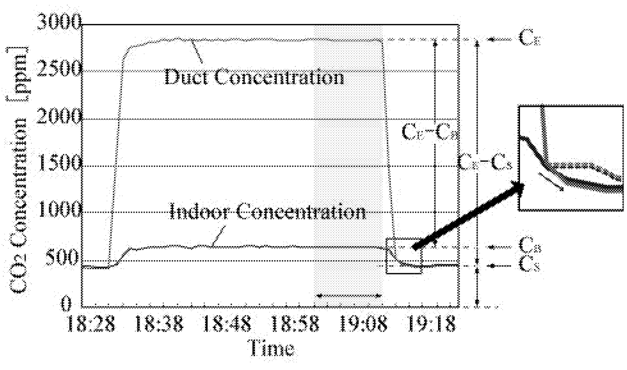
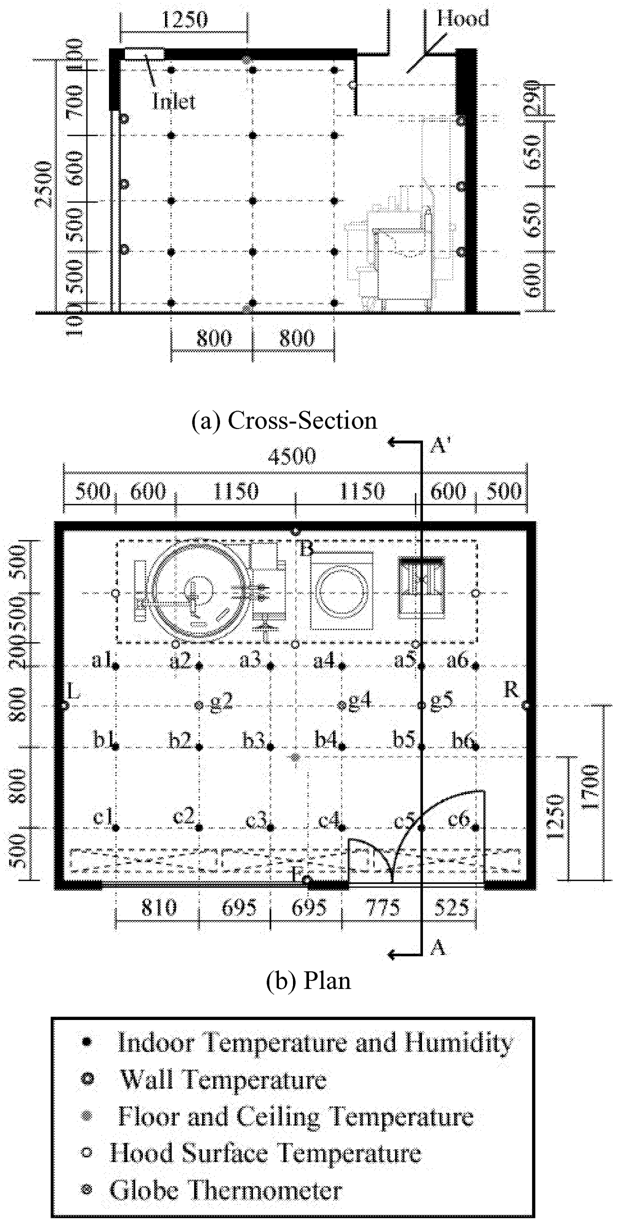


Figure 3 CO_2 Concentration

Table 2 Experimental Condition

		Low Radiative	Conventional
Exhaust Flow Rate [m^3/h]	20KQ	1190	1200
	30KQ	1790	1800
	40KQ	2390	2400
	face velocity 0.3m/s	3300	3300
	face velocity 0.4m/s	4400	4400



(a) Cross-Section

(b) Plan

Figure 4 Measurement Point

Table 3 Measurement Item

Measurement Item	Interval	Height [mm]
Indoor Temperature and Humidity	1[min]	FL+100,600,1100,1700,2400
Globe Thermometer	1[s]	FL+1100
Floor and Ceiling Temperature	1[s]	FL+0,2500
Wall Temperature		FL+600,1250,1900
Hood Surface Temperature		FL+2140
Outdoor Temperature		FL+100,600,1100,1700,2400
Supply and Exhaust Air Temperature		Inside of Duct

Table 4 Experimental Condition

		Low Radiative	Conventional
Supply Air Tempurature[℃]		18	18
Exhaust Flow Rate [m³/h]	20KQ	1190	1200
	30KQ	1790	1800
	40KQ	2390	2400
	face velocity 0.3m/s	3300	3300
	face velocity 0.4m/s	4400	4400

of concentrated exhaust. On the other hand, capture efficiency on 4400 m^3/h is about 70% in convectional kitchen. In all case, capture efficiency of low radiation kitchen is higher than that of convectional kitchen. It seems fair to say that products of combustion by kettle don't spill out in low radiation kitchen because kettle's emission tube opening is about 100 mm under the bottom of hood. As to low radiation range and fryer, products of combustion are almost captured, too. This is because that exhaust obliquely upward from emission tube opening. It is thought that capture efficiency in low radiation kitchen is high by these reasons. On the other hand, it is thought that products of combustion spill out more because that effuses 500～600mm above the floor expect a fryer.

3.2 Indoor Thermal Environment

Vertical distribution of the temperature difference from the supply air is shown in Figure 6. The temperature diffrences are the mean temperature at the same height of horizontal plane. In all cases, indoor temperature in low radiation kitchen is lower than that in conventional kitchen, and vertical distribution in low radiation kitchen is smaller than that in conventional kitchen. The difference of equipments is smaller as exhaust flow rate is larger. This can be explained by that decrement of capture efficiency as decreasing exhaust rate in conventoinal kitchen is larger than that in low radiation kitchen.

The horizontal and vertical distribution of

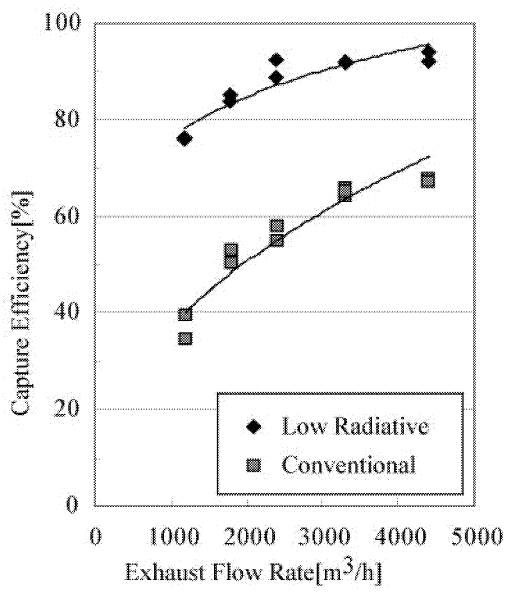
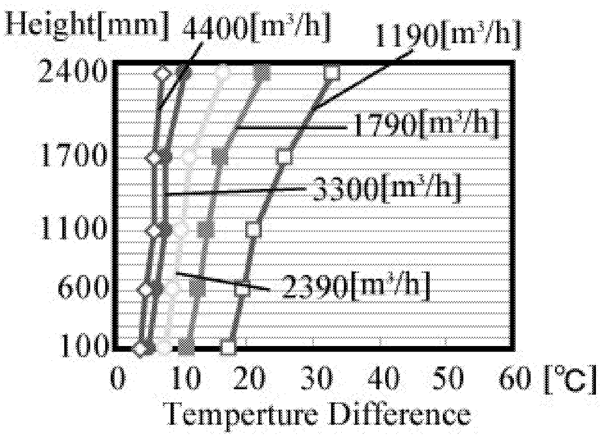


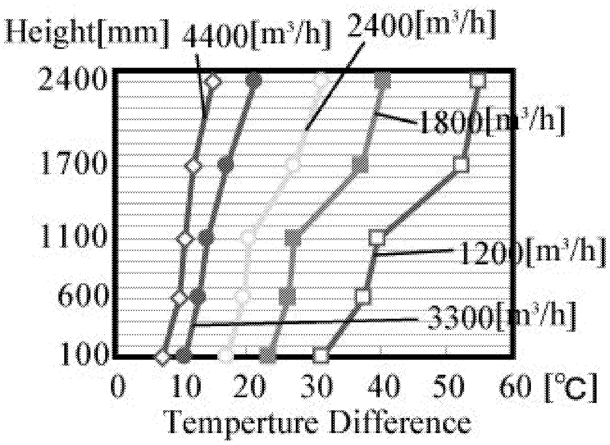
Figure 5 Relationship between Exhaust Flow Rate and Capture Efficiency

temperature defference from supply air temperature (low radiation, 2390 m^3/h and convetional, 4400 m^3/h) is shown in Figure. 7 and Figure 8. The horizontal distribution is 1100mm above the floor, and the vertical distribution is in front of the range. The shape of distribution is similar in these cases. Seeing horizontal temperature distribution in low radiation kitchen, temperature of the point a3 shows the highest value. This is because the much vapor spill out from the kettle. This much vapor is identified in fact. In low radiation kitchen, indoor temperature of the left side is lower than that of the right side regardless of the exhaust flow rate. This is because temperature of the left wall surface is lower than that of the right wall surface and heat transfer from left wall is larger than that from right wall. This is due to that the left wall is in contact with outdoor air.

The difference between globe temperature and indoor temperature is shown in Table 5. The effect of radiation in front of kettle is lower in low radiation kitchen. The difference in front of

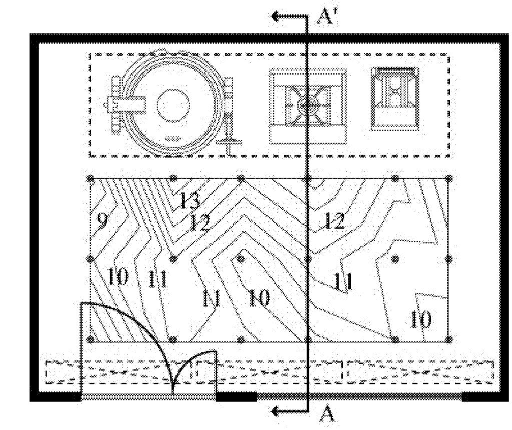


a. Low Radiation Kitchen

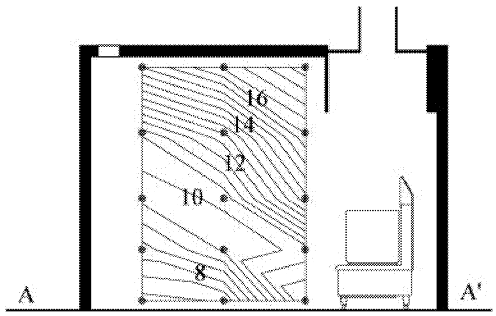


b. Conventional Kitchen

Figure 6 Plane Temperature Difference from supply air

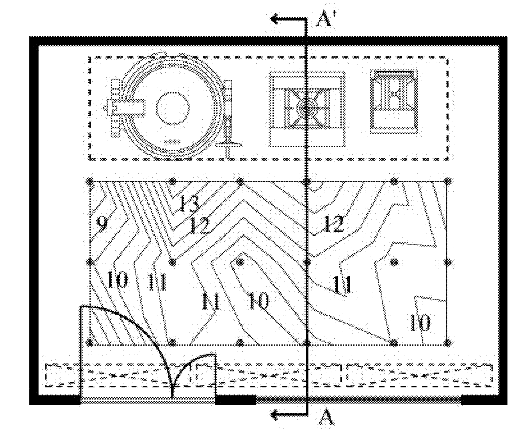


(a) Horizontal Distribution

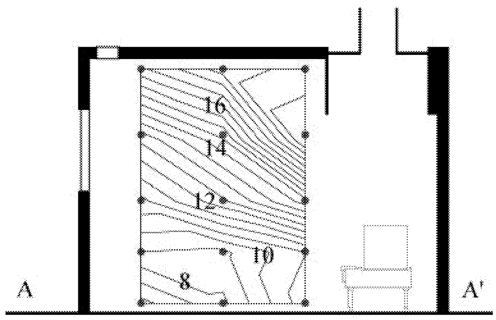


(b) Vertical Distribution

Figure 7 Distribution of Temperature Difference(Low Radiation)



(a) Horizontal Distribution



(b) Vertical Distribution

Figure 8 Distribution of Temperature Difference(Conventional)

Table 5 Difference between Globe Temperature and Indoor Temperature

		Low Radiative					Conventional				
Exhaust Flow Rate [m^3/h]		1190	1790	2390	3300	4400	1200	1800	2400	3300	4400
Globe Temperature −Indoor Temperature[℃]	g2	1.00	2.16	2.28	1.90	1.81	0.88	3.71	4.08	4.15	4.34
	g4	2.61	3.14	3.19	2.01	2.25	1.60	3.06	3.27	3.07	2.85
	g5	3.07	3.26	2.84	1.75	2.09	1.38	2.06	2.88	1.66	2.26

range and fryer is simillar though convectional equipment surface temperature is quite high. This is because indoor air temperature in conventional kitchen is higher and the effect of radiation is relatively lower. Also fire source on low radiative range is covered about 450mm above the floor, so the effect of low radiation is observed at nearer points. Therefore, it is possible that the measurement points is too far from equipments, and the easurement on nearer points is needed so as to monitored the effect of equipment surface temperature.

4. CONCLUSIONS

- Capture efficiency in low radiation kitchen is much higher than that in convectional kitchen
- The indoor temperature and vertical distribution in low radiation kitchen when exhaust flow rate is 2390 m^3/h is approximately equal to those in convectionalkitchen when exhaust flow rate is 4400 m^3/h.
- As a future prospect, capture efficiency on operating one equipment is to be investigated.
- As a future prospect, capture efficiency for cooking effluence is to be investigated.

ACKNOWLEDGEMENT

This measurement was supported by Osaka Gas Co., Ltd. and this is gratefully acknowledged.

REFERENCES

ASTM. 1999a. ASTM F 1704-99, Standard Test Method for Performance of Commercial Kitchen Ventilation System. West Conshohocken,PA; American Society for Testing and Materials.

EPRI. 1997. Commercial kitchen ventilation performance reports, TR-106493-V1 through V16, July 1996 to October 1997, Architectual Energy Corporation for Electric Power Research Institute, Palo Alto,CA.

Fisher, D.F. (1998) New recommended heat gains for commercial cooking equipment ASHRAE transactions 104(2):953-960

Knappmiller, K. D., and Schrock, D. (1997) Heat gain testing to energy balance protocol, GRI-97/0034, Gas Research Institute, February.

Kurabuchi, T., Okuda, A., Aizawa, Y., Sakamoto, A., Endoh, T., and Kondoh, Y. (2007) Influence of Cooking Operation on Indoor Environment of House Kitchens and Living Rooms Part11 Measurement Methods of Capture Efficiency under Actural Room Condition. Summaries of technical papers of Annual Meeting Architectural Institute of Japan. D Environmental engineering, Volume 2007; 707-708(In Japanese)

Momose, T., Satoh, R., Yamanaka, T., and Kotani, H. (2000) Influence of Air Current and Movement of A Person on Capture Efficiency of Kitchen Hood. Proceedings of Healthy Buildings 2000, vol.2:713-718

Smith, V.A., Swierczyna, R. T., and Claar, C. N. (1995) Application and enhancement of the standard test method for the performance of commercial kitchen ventilation systems. ASHRAE Transactions 101(1):594-605.

Swierczyna, R. T., Smith, V. A., and Schmid, F. P. (1997) New threshold exhaust flow rates for capture and containment of cooking effluent. ASHRAE Transactions 103(2):943-949.

Swierczyna, R. T., Fisher, R. D., Sobiski, P., Cole, T., and Bramfitt, M. (2005) Effect of commercial kitchen hood performance of appliance diversity and position (RP-1202). ASHRAE Research Project, Final Report.

Yamanaka, T., Satoh, R., Kotani, H., Momose, T., and Tanaka, R. (2000) Capture Efficiency of Exhaust Hood above Cooking Stoves and Fryer under Horizontal Disturbing Airflow in Commercial Kitchen. Proceedings of Healthy Buildings 2000, vol.2:719-724