# Ventilation Performance of Residential Kitchen Range Hood - Capture Efficiency of Island Hood

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ABSTRACT

An island hood, which is often installed in an island kitchen, is an exhaust range hood mounted on a ceiling independently. The capture efficiency of the island hood is obtained by experiment and CFD analysis. Examined parameters are heat input, exhaust airflow rate, mounting height of the hood, and with/without a baffle plate. The Experimental results indicate that the effect of the baffle plate is achieved in the case of large exhaust airflow rate or small heat input. Results of CFD analysis are higher than that of the experiment in the all cases.

## 1. INTRODUCTION

Recently "island kitchen" is often installed in many show houses in Japan. A cooking range is placed on the island unit that locates apart from a kitchen wall like an island and an exhaust range hood is mounted above the cooking range on a ceiling independently. This type of hood is usually called "island hood" or "central hood", while many hoods located on the wall are called "wall-mounted hood". The mounting height and position are important for the island hood because typical island kitchens have few partitions or walls between kitchens and dining/living rooms to keep occupants' interior view. Also the stylish design of the hood is desired for the good impression of the whole kitchen/dining/living room. Therefore, the design and location of the hood should be investigated as well as ventilation performance.

The capture efficiency is the basic index in ventilation performance of local exhaust devices like hoods. Some kinds of capture efficiency were proposed by many researchers (Wolbrink et al. (1992), Madsen et al. (1994), Li et al. (1996)). SHASE (2003) also mentioned the capture efficiency of the hood in the standard of ventilation requirement based on many Japanese researches concerning the ventilation performance of the residential kitchen hood in the past (Asano (1980), Narasaki et al. (1985), Suzuki (1987), Akabayashi and Murakami et al. (1989), Yu and Narasaki et al. (1993), Yamada et al. (1994) and so on). However, there are few studies on the ventilation performance of the island hood.

The purpose of this study is to examine the capture efficiency of an island hood and to propose the ventilation design method of an island kitchen considering the living room and the dining room. This paper presents the capture efficiency of the island hood by an experiment and CFD analysis. Examined parameters are heat input, exhaust airflow rate, mounting height of the hood, and with/without a baffle plate.

## 2. EXPERIMENT

### *2.1 Capture Efficiency*

The capture efficiency used in this paper is that of combustion gas obtained by so called BL-method which is standardized by the Center for Better Living (2006) as the measurement method for residential range hood. This capture efficiency is measured in a large space and the escaped contaminant does not return to the hood. Based on this method, the capture efficiency is determined using the following equation (see Figure 1).

$$\eta = Q\,(C_e - C_o) / M \qquad (1)$$

$$M = Q\,(C_{e100} - C_o) \qquad (2)$$

where:

$\eta$: Capture efficiency [-]
$M$: $CO_2$ generation rate [$m^3/h$]
$Q$: Exhaust airflow rate [$m^3/h$]
$C_o$: Background $CO_2$ concentration [-]
$C_e$: Exhaust $CO_2$ concentration [-]
$C_{e100}$: Exhaust $CO_2$ concentration where the capture efficiency is 100 % [-]

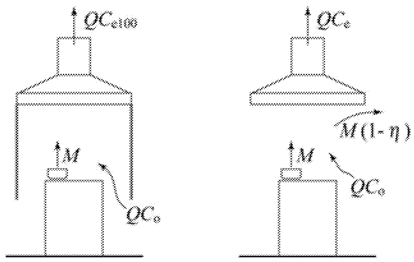


Figure 1: Definition of Variables

Experimental conditions are modified to suit the present condition, because BL-method is the measurement method for the conventional wall-mounted hood.

## 2.2 Experimental Setup

Figure 2 shows the test room assumed an island kitchen. The test room has no walls on the north side and west side, and porous net curtains are set to supply the uniform air current. As shown in Figure 3, the center of the pot is 119 mm and 172 mm away from the center of the hood. The hood is placed at the height of FL+2500 mm. An additional exhaust fan is set near the ceiling of the test room, so that the combustion gas which is not captured by the hood is able to exhaust. One burner with higher heat generation on the left side of the two burners is used. The pot is made of stainless steel and the diameter is 200 mm. The background $CO_2$ concentration ($C_o$) is measured inside the test room according to BL-method as shown in Figure 2. The exhaust concentration ($C_e$) is measured inside the exhaust duct connected to the hood. Two non-dispersive infrared gas analyzers with different measurement ranges are used for the measurement as shown in Table 1. Ultrasonic volume flowmeter is used for the measurement of exhaust airflow rate.

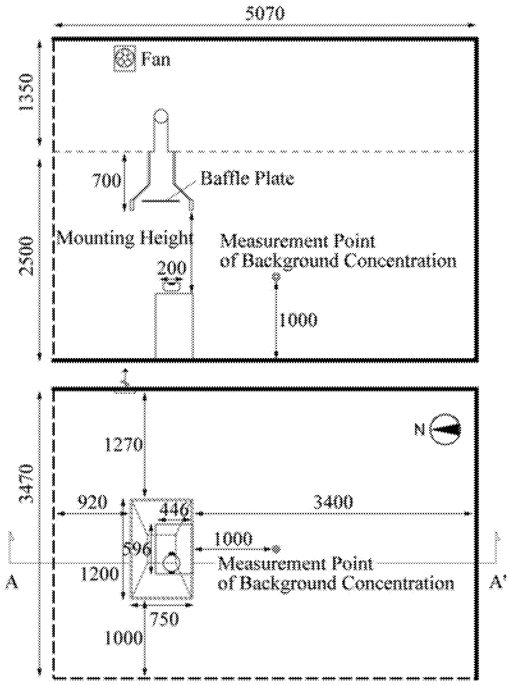


Figure 2: Test Room

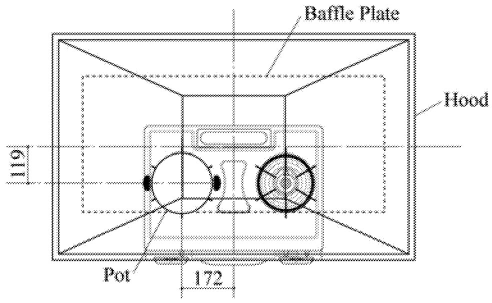


Figure 3: Layout of Pot

Table 1: $CO_2$ Analyzer

| Supplier | HORIBA | SHIMADZU |
|---|---|---|
| Model Number | VIA-510 | CGT-7000 |
| Measurement Range | 0-1000 ppm | 0-5000 ppm |
| Zero Drift | ±1.0 % F.S/day | ±1 % F.S/day |
| Span Drift | ±1.0 % F.S/day | ±1 % F.S/day |

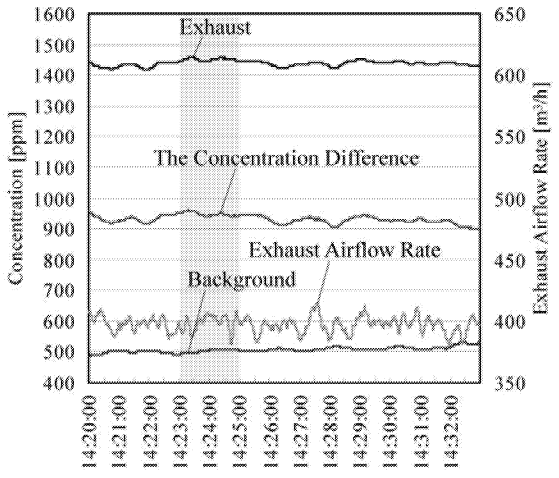
The experimental conditions are shown in Table 2. Experimental parameters are heat input, exhaust airflow rate, mounting height of the hood and with/without baffle plate. 4.2 kW of heat input is the almost maximum input value of the residential kitchen range in existence. 1.13 kW can keep the pot water boiling and is assumed to be the value in general use during cooking. The four exhaust airflow rates are selected as practical conditions (300, 400, 500, 600 $m^3/h$) from six conditions in BL-method (100, 200, 300, 400, 500, 600 $m^3/h$). The mounting height of the hood is defined as the distance from top of the range to bottom of the hood. The mounting height is changed with the setting level of the gas range. For conventional wall-mounted hoods 800 mm of the mounting height is most popular. The baffle plate is intended to attain higher sucking velocity at the bottom of the hood. When the baffle plate is equipped, the opening ratio of hood, which means the percentage of suction area to hood area at the bottom edge, is 50 %.

Table 2: Experimental Parameter

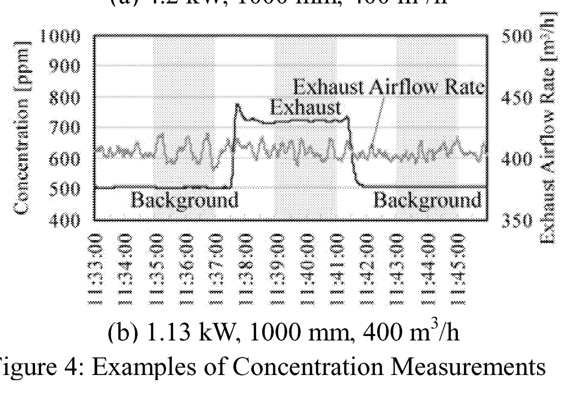
| | |
|---|---|
| Heat Input [kW] | 4.2, 1.13 |
| Exhaust Airflow Rate [$Nm^3/h$] | 300, 400. 500, 600 |
| Mounting Height [mm] | 800, 1000, 1200 |
| Baffle Plate | With / Without |

*2.3 Procedure of Concentration Measurement*

$CO_2$ concentrations of background and exhaust are measured in keeping pot water boiling. To raise the measurement accuracy, the measurement procedure is changed with heat input. Measurement intervals under both heat inputs are one minute. Examples of measured results are shown in Figure 4.




(a) 4.2 kW, 1000 mm, 400 $m^3/h$




(b) 1.13 kW, 1000 mm, 400 $m^3/h$

Figure 4: Examples of Concentration Measurements

Under the condition of 4.2 kW, the background concentration is measured by one analyzer whose measurement range is 1000 ppm for 120 seconds, the exhaust concentration is measured at the same time by the other analyzer whose range is 5000 ppm.

Under the condition of 1.13 kW, the exhaust concentration is also lower than 1000 ppm, so both of background and exhaust concentrations are measured by one analyzer whose measurement range is 1000 ppm. First the background concentration is measured for 120 seconds, next the exhaust concentration is measured for 120 seconds, then background concentration is measured for 120 seconds again. The averages of measured two background concentrations are used for the calculation of capture efficiency.

The authors will use the term "perfect capture" to refer to the condition that capture efficiency is 100 %. Perfect capture is achieved by setting aluminum boards around the hood (see Figure 1). Under this condition, background and exhaust concentrations are measured to find $CO_2$ generation rates ($M$) by the same procedures as shown in Figure 4. Theoretically, $CO_2$ generation rate depends on heat input, but the averages of measured values under different exhaust airflow rates are used for the calculation of capture efficiency to average the measurement variance. Measurement error is less than 4 % in terms of the $CO_2$ generation rate.

3. CFD ANALYSIS

*3.1 Model and Cases*

Figure 5 shows the calculation domain for CFD simulation. The dimension of hood, pot and gas range are shown in Figure 2. Air supply openings are set at lower part of walls. In the experiment the additional exhaust fan is set near the ceiling, so in CFD analysis free outflow is set as a boundary condition of the ceiling.

Analysis cases are identical to the experimental conditions shown in Table 2. As well as the experiment, the mounting height of the hood is changed by changing the height of the top of gas rang. The baffle plate is set as a panel which has no thickness at 100 mm higher than the lower edge level of the hood. CFD analysis conditions are shown in Table 3.

*3.2 Boundary Conditions*

Table 4 shows boundary conditions. Because of the calculation intended for only sensible heat, the heat generation rates which are calculated by subtracting the evaporative latent heats from heat inputs are given on the side of pot (see Figure 6). The area of the pot side is 0.08 $m^2$.

The number of mesh division is varied with the mounting height to equalize the conditions over pot. Figure 7 shows mesh system of the condition of mounting height 800 mm. It has finer meshes around the hood and the pot.

*3.3 Calculations of Capture Efficiency*

Tracer gas for combustion gas is generated circularly above the pot (see Figure 6). Capture efficiency is obtained by calculating the ratio of the gas volume through the exhaust opening to the generated gas volume. The difference between generated volume and total outflow of the gas is less than 2 % of the generated gas in the all cases.

4. RESULTS AND DISCUSSIONS

*4.1 Experimental Results*

Figure 8 shows capture efficiencies obtained by the experiment and CFD analysis. For the experimental results, the averages of the capture efficiencies of the same exhaust airflow rate are shown by dashed lines. As these figures indicate, the exhaust airflow rate has larger effect on capture efficiency at the higher mounting position. There are some conditions that the capture efficiency of 4.2 kW is higher than that of 1.13 kW, and other conditions that the capture efficiency exceeds 100 %. These might be caused by measurement error due to the difference between the concentration measurement procedure of 4.2 kW and 1.13 kW, thus the actual capture efficiency of 1.13 kW is considered to be higher than that of 4.2 kW.

From the results of heat input of 4.2 kW and the mounting height of 1000 mm and 1200 mm, it is found that the baffle plate has the positive effect in the case of large airflow rate, and the baffle plate shows the negative effect under smaller exhaust airflow rate. In the case of large airflow rate, the capture efficiency would be close to 100 % regardless of the baffle plate.

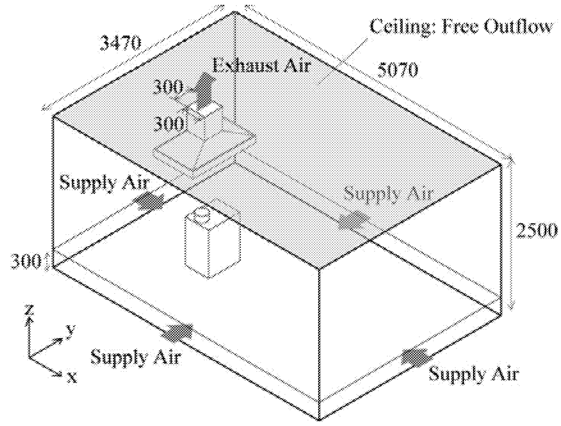



Figure 5: Calculated Domain for CFD Analysis

Table 3: CFD Analysis Conditions

| | |
|---|---|
| Code | STREAM for Windows Version7 |
| Turbulence Model | Standard k-$\varepsilon$ Model |
| Algorithm | SIMPLEC |
| Scheme for Convective Term | QUICK |

Table 4: Boundary Conditions

| | | |
|---|---|---|
| Flow | Supply Air | Inflow Velocity 0.05 [m/s], Inflow Temperature 20 [℃] |
| | Exhasut Air | Exhaust Airflow Rate 300 [$m^3$/h] ; Outflow Rate 5 [$m^3$/min]<br>Exhaust Airflow Rate 400 [$m^3$/h] ; Outflow Rate 6.6667 [$m^3$/min]<br>Exhaust Airflow Rate 500 [$m^3$/h] ; Outflow Rate 8.3333 [$m^3$/min]<br>Exhaust Airflow Rate 600 [$m^3$/h] ; Outflow Rate 10 [$m^3$/min] |
| | Ceiling | Free Outflow |
| Walls | | Standard Log-low |
| Thermal | | Adiabatic, Standard Log-low |
| Heat Generation (on Side of Pot) | | Values which Deduct Evaporative Latent Heat from Input<br>Heat Input 4.2 [kW] ; 31190 [W/$m^2$]<br>Heat Input 1.13 [kW] ; 7025 [W/$m^2$] |

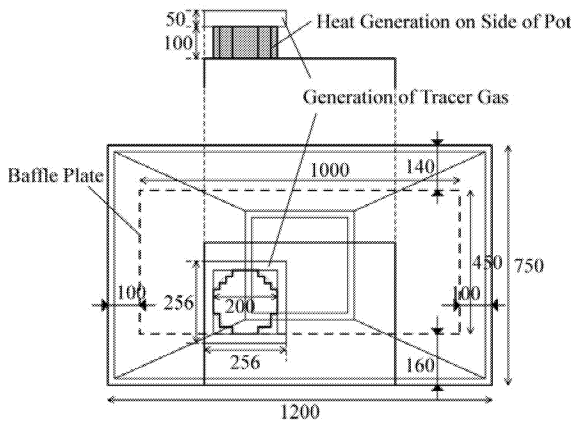



Figure 6: Layout in CFD Analysis

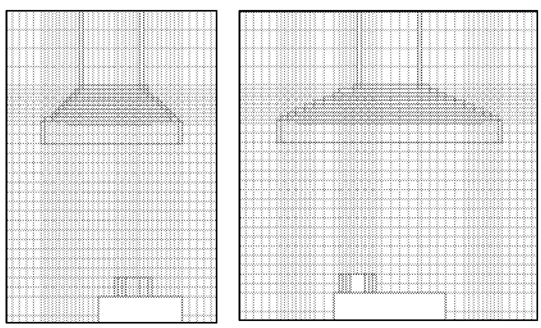
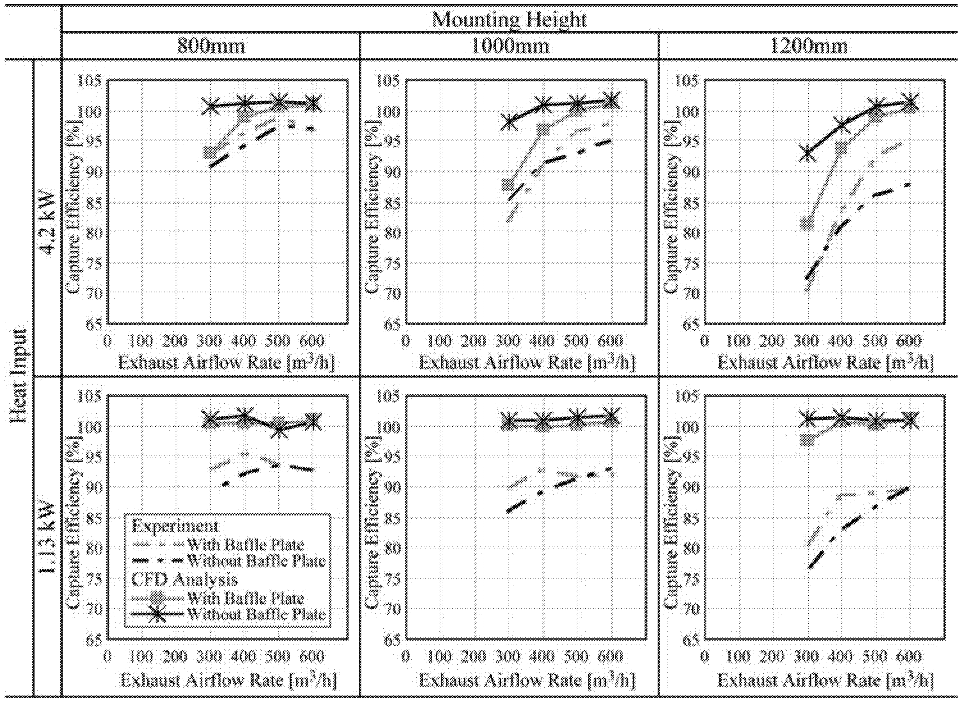


Figure 7: Mesh System

While the effect of the baffle plate would be negative if the exhaust airflow rate is decreased.

The baffle plate is equipped for kitchen hood to improve capture performance by decreasing the suction area and increasing velocity around the baffle plate. Under the conditions with the baffle plate, thermal plume changes its direction horizontally by collision against the baffle plate and is exhausted from the gap between the hood and the baffle plate. Therefore, it would appear that the ratio of sucking velocity to horizontal velocity of plume directly affect the capture efficiency. In the case that the sucking velocity is large compared to the horizontal velocity of plume, namely large exhaust rate or small heat input, the capture efficiency would be high. By contrast, in the case that the sucking velocity is small compared to the horizontal velocity of plume the capture efficiency would be low. On the other hand, under the conditions without the baffle plate thermal plume is exhausted from the center of the hood. Therefore the change of the capture efficiency would be smaller than the cases with the baffle plate when either exhaust airflow rate or heat input is changed. These descriptions would give a good account for the result that the effect of the baffle plate is achieved in the case of large exhaust airflow rate or small heat input. Similarly, when the mounting height is raised, the horizontal velocity of plume decreases and the effect of the baffle plate would be large.




*4.2 Results of CFD Analysis*

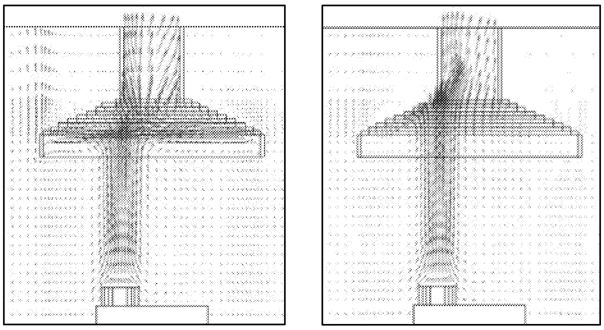
The capture efficiencies obtained by CFD analysis are higher than that by the experiment in the all cases. The reason is that the spreading width of thermal plume calculated by CFD analysis is smaller than that of real thermal the plume. It is well known that using the model given only heat generations as boundary conditions makes the width of plume smaller.

Capture efficiencies in the case without the baffle plate exceed those with the baffle plate. This could be explained by that the effect of the spreading width in the case without the baffle plate becomes larger. The collision of plume against the baffle plate makes the large spreading width regardless of the spreading width of thermal plume.

In the case of heat input of 4.2 kW and mounting height of 1000 mm and 1200 mm, as the tendency of the analysis results is similar to the experimental results, the effect of the exhaust airflow rate on the capture efficiency could be simulated adequately.

Figure 9 and Figure 10 show the velocity distribution and the concentration distribution in the cross section passing through the center of the pot under the condition of heat input of 4.2 kW, the mounting height of 800 mm and exhaust airflow rate of 300 $m^3$/h. As these figures indicate, thermal plume is adequately exhausted from the center of hood under the condition without the baffle plate, while thermal plume leaked due to the collision against the baffle plate under the condition with the baffle plate.

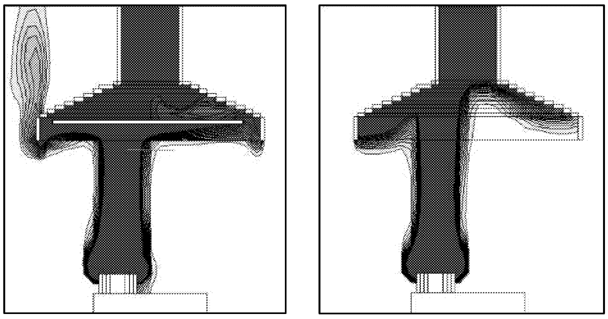
In the case of heat input of 1.13 kW, all capture efficiencies are about 100 %. It is inferred that thermal plume is enough small not to be affected by the mounting height and the baffle plate.



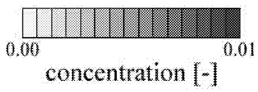
y-z cross section　　　y-z cross section

(a) With Baffle Plate　　(b) Without Baffle Plate

Figure 9: Distribution of Velocity



y-z cross section　　　y-z cross section




(a) With Baffle Plate　　(b) Without Baffle plate

Figure 10: Distribution of $CO_2$ Concentration

## 5. CONCLUSIONS

- The exhaust airflow rate has larger effect on capture efficiency at the higher mounting position.
- The baffle plate effectively works in the case of large exhaust airflow rate or small heat input.
- The capture efficiencies by CFD analysis are higher than that by the experiment in the all cases.
- The effects of the exhaust airflow rate and the baffle plate on the capture efficiency could be simulated adequately by CFD analysis.

## ACKNOWLEDGMENT

The authors are grateful to Osaka Gas Co., Ltd for supporting the part of this research.

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