RESEARCH ON VENTILATED CEILING SYSTEM FOR COMMERCIAL KITCHEN

Part 2 Field Measurement of Indoor Thermal Environment and Ventilation Performance

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Abstract
The precise measurements of the indoor thermal environment and the ventilation performance of a commercial kitchen served by the ventilated ceiling system were conducted.

Precise measurements
To more precisely understand the indoor thermal environment, precise temperature measurements were conducted when the kitchen was not used for cooking practice. Points of measurements were as shown in Figure 7 in Part 1. The measurements were conducted either by operating only the gas and electromagnetic ranges or fully operating the cooking equipment listed in Table 1. Figure 1 shows vertical temperature distribution for the two operational states of the cooking equipment. The result shows:

1) The temperatures below 1.1m from the floor were not affected by the operation of the cooking equipment, and were always between 25 to 27°C, forming a good environment in the occupied zones.

2) In front of the electromagnetic range (A3), the temperature fluctuation by height was small. This was likely attributable to that 1) the energy produced by the range was small, and 2) the temperature near the floor was high since the point was far from the air inlets. A globe thermometer showed a temperature 1°C higher than the room temperature, showing small effects of radiation.

3) The temperature in front of the gas range (D5) exceeded 50°C near the ceiling when the cooking equipment was in full operation. A very sharp temperature gradient was formed above 1.7 m from the floor. The globe thermometer showed a temperature 10°C higher than the room temperature, suggesting large effects of the radiation from the ceiling surface as well as the heat of the cooking equipment.

4) At A5, which was at the opposite side of the central cooking table from the electromagnetic range, the temperature near the ceiling was almost 40°C, which was higher than that at the front of the electromagnetic range. This was likely attributable to the heat from the gas range was retained within the raised ceiling.

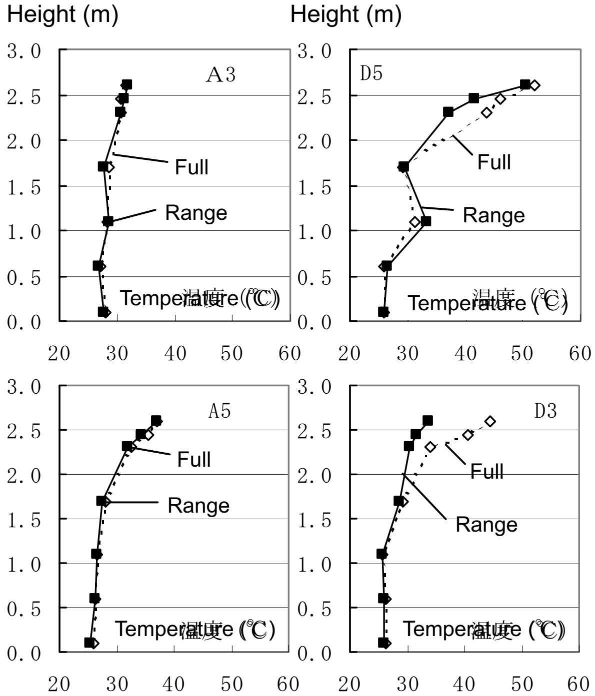
5) At D3, which was at the opposite side of the central cooking table from the gas range, the temperature near the ceiling was almost 45°C when the convection oven by the wall was in operation. The temperature was only 35°C when only the electromagnetic and gas ranges were being operating, suggesting that the temperature was not affected by the heat of the gas range due to sagged ceiling.

6) The results almost agreed with the results of our previous numerical simulation.

7) Temperatures were also measured by changing the ventilation rate and the temperature of the supply air. The indoor thermal environment slightly deteriorated, but the difference was not significant since the temperature of the supply air was changed only by 1 to 2°C, and the duration during which the ventilation was changes was short.

Table 1 Full operation of cooking equipment

･Gas ranges
Two big burners at full power
･Electromagnetic ranges
At heating power equivalent to the gas range
･Fryer
Oil temperature 170℃
･Tilting pan
Water bath, 100℃
･Steam convection oven
Oven, 170℃
･The steam convection oven and the tilting pan were operated for 30 minutes, were opened, and stopped.



Full: Full operation, Range: Rages only

Figure 1 Vertical temperature distribution by precise measurement

Evaluation using thermal comfort indices

Table 2 shows the measurements when the ranges were being operated, and SET* and PMV values that were derived by computation. The relative humidity was assumed to be 54.5% throughout the room, the metabolism was assumed to be 1.2 met, and the amount of clothing was assumed to be 0.7 clo.

1) At all points, SET* values were around 30°C, which is an evaluation of "relatively warm" and is a good indoor thermal environment for a kitchen.

2) When the values were compared between D5, in front of the gas range, and A3, in front of the electromagnetic range, D5 showed a room temperature that was 0.3°C higher and a MRT that was 7.4°C higher than those at A3. This suggests that the effect of radiation by the combustion of gas was large.

Evaluation by age of air

Measurement methods

To determine the efficiency to replace air by fresh air at each point in a kitchen, measurements were conducted using tracer gas.

As the tracer gas, sulfur hexafluoride (SF6) was used, which is non-toxic and odor-less. Since the

Table 2 Measurements of indoor thermal environment indices

Measurement points			
A3	A5	D3	D5
Room air Temperature (℃)			
26.2	26.4	25.7	26.5
Mean Radiant Temperature (℃)			
31.4	31.4	33.6	38.8
Air Velocity (m/s)			
0.1	0.3	0.2	0.2
SET* (℃)			
29.8	29.0	30.5	31.5
PMV (-)			
1.4	1.1	1.4	1.7

kitchen was ventilated as frequently as approximately 35 room air changes per hour, it was possibly difficult to precisely measure the efficiency due to the time constant of multi-gas monitors (B&K1302), the time needed for the gas to pass a sampling tube, and the measurement frequency of the multi-gas monitors. Since it was difficult to directly introduce the tracer gas into the air supply duct due to the structure of the kitchen, air samples were constantly collected in sampling bags (Tedlar bags) using a pump while decaying the tracer gas (Kvisgaard 1995). Figure 2 shows the points at which sampling bags were set to measure the concentration of the tracer gas. The procedure of measurement is:

1) Chinks in the inner doors were sealed up. A fix amount of the tracer gas was dosed while stopping the ventilated ceiling system. The gas was then agitated to spread uniformly throughout the kitchen with fans.

2) After checking that the concentration of the tracer gas became uniform at the six points of measurements using the multi-gas monitors, we stopped the dosing of gas, and simultaneously started operation of the cooking apparatuses, the ventilated ceiling system, and small pumps installed at the points of measurements to collect samples in sampling bags.

3) After checking that the concentration of the tracer gas was reduced to 1% of the initial concentration or lower, we simultaneously stopped all the small pumps, sealed the sampling bags with pinch cocks, and collected the sampling bags.

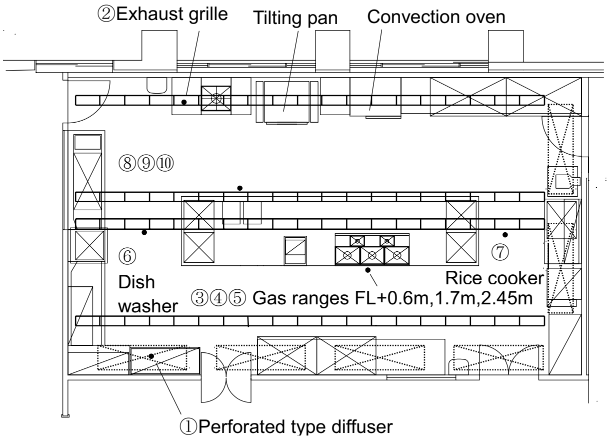


Figure 2 Points of measuring tracer gas concentration

Table 3 Computational equation of local mean age of air

$$\tau_p = (C_p - C_i)\times(\tau_o - \tau_{stop})/(C_o - C_b)$$

τ_p	: Local mean age of air [s]
τ_o	: Time to start the small pump [t]
τ_{stop}	: Time to stop the small pump [t]
C_o	: Initial concentration of the tracer gas [ppm]
C_b	: Background concentration of the tracer gas in the kitchen=0 [ppm]
C_p	: Concentration of the tracer gas at the point of measurement=(sampling bag) [ppm]
C_i	: Concentration of the tracer gas at the point of measurement=(supply air sampling bag) [ppm]

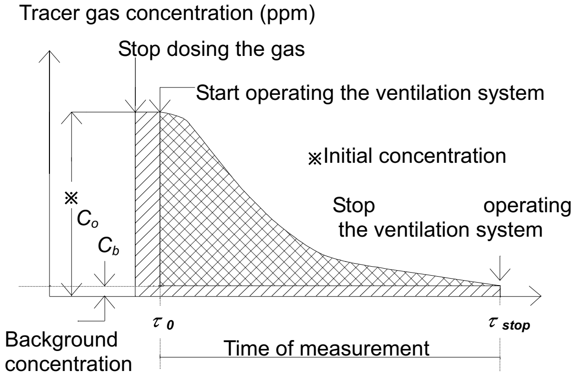


Figure 3 Concept of the sampling bag method

Table 4 Patterns of the measurement

Pattern	Use of cooking apparatuses
①	No cooking apparatuses used
②	Only the electromagnetic range used
③	Only the gas range used
④	Both the electromagnetic and gas ranges used
⑤	Both the electromagnetic and gas ranges used (with a hanging wall)

4) The concentration of the tracer gas in each of the sampling bags was measured, and the local mean age of air at each point was calculated.
Figure 3 shows the concept of the sampling bag method, and Table 3 shows the equation used to determine local mean age of air. The patterns of measurement were changed by the use or no use of the electromagnetic range and the gas range. Based on the air flow computation described in Part 1, a hanging wall was installed to imitate lowered air inlets and avoid the short circuit (Pattern 5). Table 4 shows the measurement patterns, and Figure 4 shows the installation of the hanging wall for Pattern 5.

Results of the measurement

Table 5 lists the concentrations of the trace gas at the points of measurement, and Table 6 lists the local mean age of air. In general, the air age was higher at higher points of measurement in front of the gas range. This was likely attributable to 1) the strong ascending current that was produced by gas combustion, and 2) fresh air that was constantly supplied from the lower part since the points of measurement were near to the air inlets of the ventilated ceiling system. On the other hand, in front of the electromagnetic range showed almost no change in air age by height. This was likely attributable to 1) there was little effect of combustion, and 2) the electromagnetic range was located far from the air inlets. Pattern 2, which used only the electromagnetic range, showed higher air ages than Pattern 1, which used no ranges, in general. Pattern 3, which used only the gas range, showed a slightly larger difference in air age by elevation in front of the gas range than Patterns 1 and 2. Pattern 4 showed younger air ages than Pattern 5 at all points of measurement, contradicting to the results of our numerical simulation analysis. There possibly was a time lag between the start of the ventilated ceiling systems and the collection of air samples in sampling bags for Pattern 4. Therefore, this analysis could not determine the effect of the hanging wall on the ventilation performance. The experimental precision should be further improved to evaluate air ages using sampling bags in an environment that is frequently ventilated. This evaluation method also had a tendency to derive slightly larger air ages.

Visualizing air currents using smoke

Smoke was generated for a certain period of a time using a smoke machine (ROSCO) placed on the floor in the middle of the kitchen while operating the ventilated ceiling system and the electromagnetic and gas ranges to visualize air currents after ceasing the generation of the smoke. Figure 5 shows a view of the experiment. As in the conventional displacement ventilation system, which has air inlets near the floor or at the lower parts of the walls, fresh air was introduced into the lower part of the kitchen and pushed the smoke upward.

Conclusion

1) The precise temperature measurements showed that the occupied zone was maintained in a good indoor thermal environment even when the kitchen was ventilated only 35 times per hour.
2) The displacement ventilation successfully formed thermal stratification.
3) The thermal comfort indices also showed that the kitchen had a good indoor thermal environment.
4) The ventilation performance of a ventilated ceiling system was evaluated by analyzing the local mean age of air and visualizing air flow using smoke. Our examination showed that the kitchen was displacement ventilated.
5) The positional relationships among heating apparatuses, air inlets, and exhaust air outlets determine the ventilation performance.

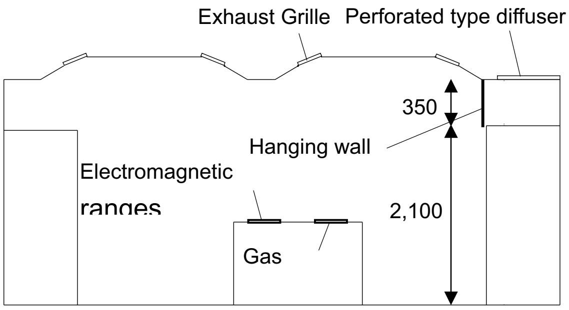


Figure 4 Installation of a hanging wall

Figure 5 Visualization with smoke

6) An analysis using sampling bags is effective to roughly estimate ventilation performances, but the precision of measurements should be improved.

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References

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Table 5 Concentration of tracer gas at each point

Duration of sampling [s]					
Pattern	1	2	3	4	5
	697	736	454	438	478
Concentration [ppm]					
Pattern	1	2	3	4	5
Initial	128.8	111.5	118.2	126.5	119.4
Supply air	11.9	10.3	6.6	4.1	7.1
Exhaust	96.3	120.9	109.2	79.2	110.3
G.Range+0.6	59.6	82.2	63.1	45.3	66.3
G.Range+1.7	81.2	95.0	88.8	64.0	90.1
G.Range+2.45	96.3	132.5	115.8	74.4	101.8
D.Washer+1.7	62.0	91.8	77.8	68.8	125.7
R.Cooker+1.7	65.8	95.6	81.2	53.7	93.9
E.Range+0.6	112.2	141.3	139.6	85.8	127.1
E.Range+1.7	102.3	143.2	147.6	96.2	141.6
E.Range+2.45	97.8	136.1	135.3	96.6	142.1

Table 6 Local mean age of air at each point

Local mean age of air [s]					
Pattern	1	2	3	4	5
Supply air	0.0	0.0	0.0	0.0	0.0
Exhaust	456.7	730.1	393.9	260.0	413.0
G.Range+0.6	258.1	474.6	216.9	142.6	236.9
G.Range+1.7	375.0	559.1	315.6	207.4	332.2
G.Range+2.45	456.7	806.7	419.3	243.4	379.0
D.Washer+1.7	271.1	538.0	273.4	224.0	474.6
R.Cooker+1.7	291.7	563.1	286.4	171.7	347.4
E.Range+0.6	542.8	864.8	510.7	282.8	480.2
E.Range+1.7	489.2	877.3	541.4	318.8	538.3
E.Range+2.45	464.8	830.5	494.2	320.2	540.3