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Thermal Environment and Energy Conservation in a Commercial Kitchen with "SUZUCYU" Low Radiation Cooking Appliance

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1. ABSTRACT

Low radiation kitchen equipment can improve the working environment in a kitchen because the surface temperature of the equipment is lower compared with conventional equipment. Moreover, the combustion exhaust is efficiently exhausted, so the air-conditioning energy can be reduced accordingly. In this report, the energy conservation effect and working environment comfort of low radiation kitchen equipment were quantitatively evaluated by comparing against conventional cooking appliance. Furthermore, a kitchen in a school with substitution ventilation (one-way flow) was targeted. With this setup, the air supply opening and the exhaust vent were set up on opposite sides of the kitchen so that the air-conditioning could smoothly exhaust air to the outside. The thermal environments of the kitchen when low radiation and conventional cooking appliances were installed were analyzed by simulation, and compared. The objective was to clarify the influence of low radiation equipment on the kitchen environment. Additionally, the heat balance of important cooking equipment was measured and analyzed by CFD in order to evaluate the thermal environment in an actual kitchen.

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2. BODY OF PAPER

2.1 Introduction

In a commercial kitchen, there are a lot of appliances and equipment installed for cooking, ventilation and air-conditioning. In-flowing or out-flowing air at various openings greatly influences air currents as a whole and makes the airflow complex and well-mixed. Conventional cooking appliances have high temperature on outside surfaces. These factors adversely affect the efficiency of air-conditioning and the thermal environment.

Low radiation type gas cooking appliances have been developed with the features of lower outside temperature and ducted combustion gas exhaust. They have been employed in many commercial kitchens in recent years. Displacement ventilation systems can avoid mixing between conditioned air and supplied outside air. A commercial kitchen furnished with a set of low radiation type gas cooking appliances with displacement ventilation systems is expected to create good quality air and thermal environments.

Firstly, an experimental study was done to compare a set of conventional gas appliances with a set of low radiation gas appliances in terms of thermal environment and energy consumption. Secondly, a simulation study of comparisons was made between the conventional and the low radiation type appliances in a displacement ventilation (one-way-flow) kitchen. Thirdly, a simulation study was also done for an actual commercial kitchen models with conventional and low radiation type appliances. All of the studies indicated the advantages of low radiation appliances.

2.2 Analytical Model in the Experimental Laboratory

2.2.1 Experimental Overview

Two laboratories that replicated commercial kitchens were produced for the test. The two rooms were designed so that the size was the same and the thermal environment was equal for the most part. The low radiation cooking appliances (pot cooker, soup stove and fryer) were set up in one of the laboratories, and the conventional cooking appliances were set up in the other. Figure 1 shows the laboratory. Cooking was mimicked by filling each cooking appliance about 80% with water, When water decreased by evaporation during the experiment, water was promptly replenished. A pot cooker and a soup stove were measured while boiling. A fryer usually uses oil, so water of a constant amount was always replenished and kept from boiling.

The indoor temperature, wall surface temperature and radiant temperature were measured. Three measurement points temperature (height FL+0.6m, FL+1.1m, and FL1.7m) were used for the indoor temperature and the wall surface. The radiant temperature was assumed to be 1 m on each side of a cooking appliance (height FL+1100). Figure 2 shows the measurement points.

There are eight experimental conditions of varying load factor consisting of cooking appliance heat generation and an amount of ventilation. Table 1 shows experimental conditions.

2.2.2 Results and Considerations

Figure 3 shows the room temperature at a 100% load from the cooking appliances. In the laboratory with the low radiation cooking equipment, the room temperature tended to be lower under all conditions using a 100% load from cooking appliances, compared with the conventional model. The ventilator volume of the commercial kitchen is by law in Japan 40 times the theoretical amount of exhaust gas at the gas kitchen equipment (40kQ). The laboratory with the low radiation cooking appliances is lower in temperature than the laboratory with the conventional cooking appliances by about 10°C at a height of FL+1.1m and by 15°C at a height of FL+1.7m when experimenting with 40KQ of ventilation.

The influence that the cooking appliances have on air-conditioning load is evaluated at the load conversion rate. The load conversion rate is calculated from Figure 4. The air-conditioning load in the kitchen can be simply evaluated by assuming the influence of the sensible heat and the latent heat to be the same.

Figure 5 shows the calculation results for the load conversion rate. It is understood that there is little difference in load conversion rate by turning on calories. The load conversion rate was about 25% in the conventional appliance kitchen, and about 12.5% in the low radiation appliance kitchen.

Figure 6 shows the relationship between ventilator volume and SET* (Standard new Effective Temperature) at pot cooker loads of 100% and 50%. A clothing amount 0.5 clo and a metabolizing (light work) amount of 1.8 met were applied to the calculation of SET *. The low radiation appliance lowers SET * more than the conventional appliance under all conditions, and it was understood to be comfortable. When the conventional appliance was compared with the low radiation appliance, the difference of SET * grew in such a way that the smaller the ventilator volume, the larger the turning on calorie is. SET * at a ventilation hood surface wind velocity of 0.3m/s and 100% load was about 30 °C with the conventional appliance. To assume it by the low radiation type below the equal to this condition, it has been understood that it finishes being satisfactory in amount 40KQ of ventilation.

2.3 Simulation Study for One-Way-Flow Kitchen

2.3.1 Indices in the Kitchen

The thermal environments in a commercial kitchen in a school with the displacement ventilation system were compared between the two cases of a lineup of gas cooking appliances consisting of low radiation appliances and a lineup consisting of conventional appliances. The results are shown in Fig. 7. The low radiation appliances consisted of five pot cookers and four rice cookers, while the oven and the gas range were assumed to be of conventional specifications. The supply air (SA) flows downward from a duct on the ceiling along the entire span on one side. The cooking appliances were arranged on the wall opposite the SA, and an exhaust hood was installed above the cooking appliances. Three worktables were set up in the center of the kitchen. The height of the worktables was assumed to be 900 mm, with an installation space of 200 mm between the worktable surface and the floor, and air was allowed to flow through that space. The refrigerator, food stocker and other units were appropriately arranged.

Figure 8 shows the distribution of the vertical air temperature, wind speed, water vapor, MRT (Mean Radiant Temperature), and SET* (Standard new Effective Temperature). The top edge corresponds to a distance of 0.5 m from the pot cookers. The space in this section above a floor level of 0.0-1.9 m is considered to be workspace, and the average values for this workspace are shown in parentheses in the figure. The difference in MRT represents the difference in the radiation environment between the conventional cooking appliance and low radiation type cooking appliance; the average MRT is 34.7°C in the low radiation cooking appliance, while it is 41.1°C in the conventional cooking appliance. The maximum MRT near the fryer (oil temperature of 180°C) was 52.2°C for the conventional cooking appliance and 44°C for the low radiation type cooking appliance. The average SET* became 31.7°C for the conventional cooking appliance and 29.3°for in the low radiation type cooking appliance. Thus, the low radiation cooking appliance was found to be effective towards improving the working environment.

2.3.2 Thermal Environment and Energy Conservation

The room temperature in the workspace rose in the kitchen with the conventional appliances compared with the case of low radiation appliances when the temperature of the supplied air was 25°C (Case 1). Table 2 shows the results of changing the temperature of the supplied air in order to obtain the same average room temperature and sensible temperature in the kitchens with the conventional appliances and the low radiation appliances. Case 1 serves as the baseline, while, in Cases 2 and 3, the average room temperature and SET* of the conventional cooking appliances are the same in the low radiation type cooking appliances. It was found that the cooling load must be increased by 6% in the conventional cooking appliance to have the same average temperature in the workspace as with the low radiation type cooking appliance. It was also found that the cooling load must be increased by as much as 43% to have the same SET* with the conventional cooking appliance as with the low radiation type cooking appliance.

2.4 Simulation Study for a Kitchen of Noodle Restaurant

2.4.1 Measurement of Heat Balance of Cooking Appliances

In order to improve the accuracy of simulation, the heat balance of the cooking appliances and the thermal environment around the appliances were measured. Six types of appliances were targeted: pot cooker, soup stove, rice cooker, noodle boiler, fryer and small rice cooker. Measurements were taken for the aforementioned six types of appliances for each the low radiation appliances and the conventional appliances. The characteristics of each appliance were verified individually by measuring the amount of water evaporation, temperature, concentration and flow rate of exhaust gas, temperature distribution around the cooking appliance and surface temperature of each cooking appliance. To guard against external disturbances such as air-conditioning, cooking appliances were enclosed in vinyl sheets and measurements were made within the enclosed space (test kitchen). The test kitchen was 3.5 m in width, 3.6 m in depth and 2.3 m in height. Ventilation air volume within the enclosures was kept constant at all times. The temperature and air flow rate within the enclosures were measured at fixed intervals. The same amount of water evaporation was used for the low radiation appliance and conventional appliance in order to compare the two appliances under the same conditions. The improvement of simulation accuracy can be expected by applying the characteristics of each cooking appliance.

Moreover, the thermal environment of the test kitchen was evaluated from the measurement data. The temperature distribution of the test kitchen where the pot cooker was installed is shown in Fig. 9. This particular figure represents a cross-section at a point 40 cm in front of the pot cooker. In comparing the low radiation appliance and conventional appliance in Fig.9, a difference was 9.7˚C at the representative point (point in A in figure) and a difference was 4.2˚C in average temperature.

2.4.2 Example Application to the Kitchen of Noodle Restaurant

The thermal environment of the kitchen of noodle restaurant was analyzed by CFD using the measurement results obtained for each appliance as analytical conditions. A schematic diagram of the kitchen that was subjected to CFD analysis is shown in Fig. 10. A comparison was made between a kitchen equipped entirely with all conventional cooking appliance and a kitchen equipped entirely with low radiation type cooking appliance. These appliances included a soup stove, fryer, rice cooker, noodle boiler. Figure 11 shows CFD results. The average temperature in the kitchen with low radiation cooking appliances was about 5˚C lower than the kitchen with conventional appliances. And, the temperature difference at the representative point (point in A in figure) was about 15˚C.

2.5 Concluding Remarks

The temperature distribution, influence on air-conditioning load and comfort were evaluated by appliance type for a simulated kitchen equipped with low radiation appliances and a similar kitchen equipped with conventional appliances. The room temperature of the kitchen outfitted with low radiation appliances tended to be lower than in the kitchen with conventional appliances under all simulated conditions. The difference in comfort level between the two kitchens increased as ventilation air volume decreased and the charged heating quantity increased.

In the studied school kitchen, it was shown that the thermal environment in the kitchen was improved by installing low radiation appliances of low surface temperature. Especially, it was shown effective to change the pot cooker to a low radiation model. To keep the same average room temperature and same sensible temperature as in the kitchen with low radiation appliances, the air-conditioning energy in the kitchen with the conventional appliances was 6% and 43% higher respectively. The temperature, humidity, heating load and other parameters of an actual commercial kitchen were measured and confirmed the validity of this analysis.

The thermal environment of kitchen in restaurant was analyzed by CFD. A comparison of results showed a clear difference in the thermal environments of the kitchen when outfitted with low radiation appliances than when outfitted with conventional appliances.

Acknowledgment

Authors thank Hiromasa Tanaka and Yoshiko Ogami from Nikken Sekkei Ltd. for their valuable comments.

3. TABLES

Table 1 Measuring conditions of ventilation air volume and equipment load rate

	(Conventional)				(Low Radiation)				
	Fryer	Soup stove	Pot cooker	Total	Fryer	Soup stove	Pot cooker	Total	
Kitchen appliance heat generation quantity (kw)	10.5	17.4	37.2		8.37	20.9	34.9		
V=20KQ	195	324	692	1,211	156	389	649	1,194	
V=30KQ	293	485	1,038	1,816	234	583	974	1,790	→(1)
V=40KQ	391	647	1,384	2,422	311	777	1,298	2,387	((2)

(Ventilating air volume calculated from hood surface wind velocity (CMH)

	Hood area 1/3	Hood area 2/3	Overall	
Hood surface wind velocity 0.2 m/s	840	1680	2.520	
Hood surface wind velocity 0.25 m/s	1050	2100	3,150	((3)
Hood surface wind velocity 0.3 m/s	1260	2520	3,780	((4)
Hood surface wind velocity 0.4 m/s	1680	3360	5,040	
Hood surface wind velocity 0.5 m/s	2100	4200	6,300	

(Measuring date and measuring conditions

			Conventional kitchen load rate			Low Radiation kitchen load rate		
No.	Measuring date	Ventilation air volume	Pot cooker	Soup stove	Fryer	Pot cooker	Soup stove	Fryer
1	08/01/11	30KQ((1)	100%	100%	100%	100%	100%	100%
2	08/01/15	40KQ((2)	100%	100%	100%	100%	100%	100%
3	08/01/16	0.25m/s→(3)	100%	100%	100%	100%	100%	100%
4		0.3m/s→(4)	100%	100%	100%	100%	100%	100%
5	08/01/17	0.3m/s→(1)	50%	50%	100%	50%	50%	100%
6		0.25m/s→(2)	50%	50%	100%	50%	50%	100%
7	08/01/18	40KQ→(3)	50%	50%	100%	50%	50%	100%
8		30KQ((4)	50%	50%	100%	50%	50%	100%

Table 2. Analytical Results

	Low RadiantRadiation	Conventional		
	Case 1	Case 1	Case 2	Case3
Supply air [°C.]	25.0	25.0	24.5	21.6
Average temperature [°C]	25.6	26.1	25.6	--
SET* [°C]	29.3	31.7	--	29.3
Air-conditioning load ratio	1.00	1.00	1.06	1.43

4. FIGURES

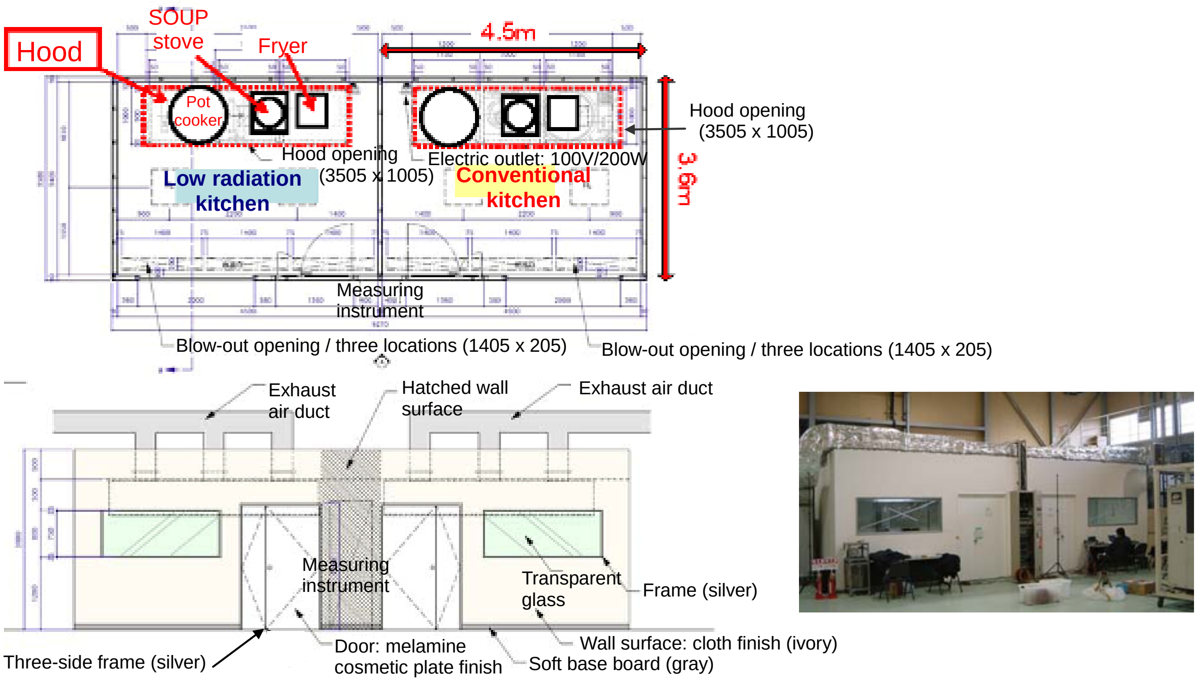


Figure 1 Outline of experimental laboratory

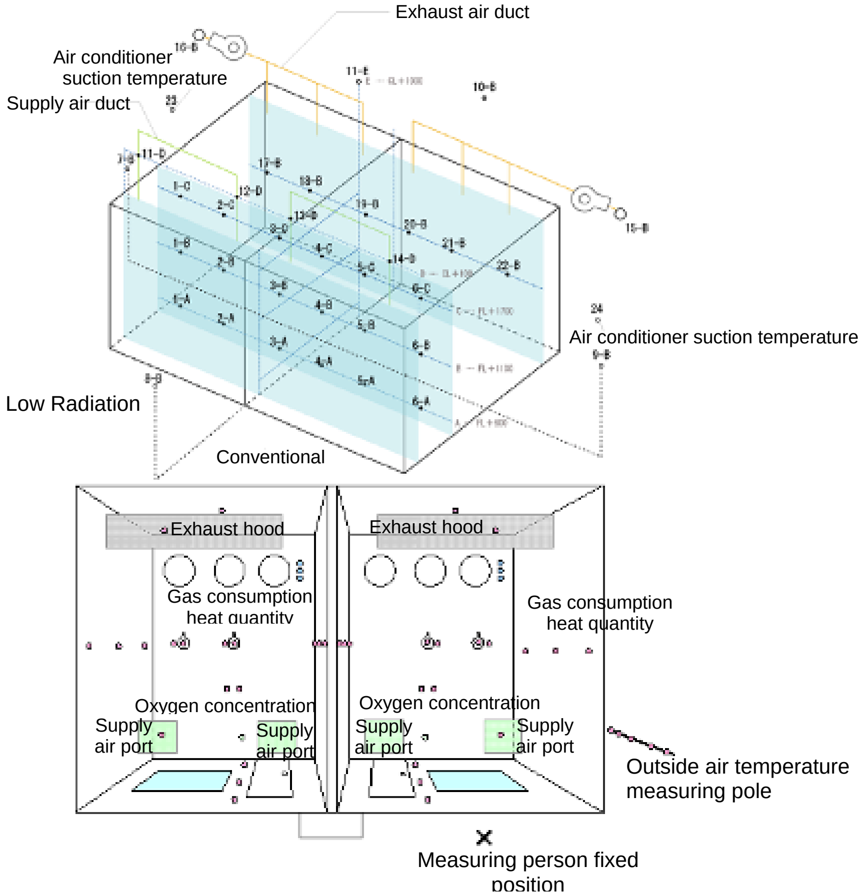


Figure 2 Positions of temperature measuring points

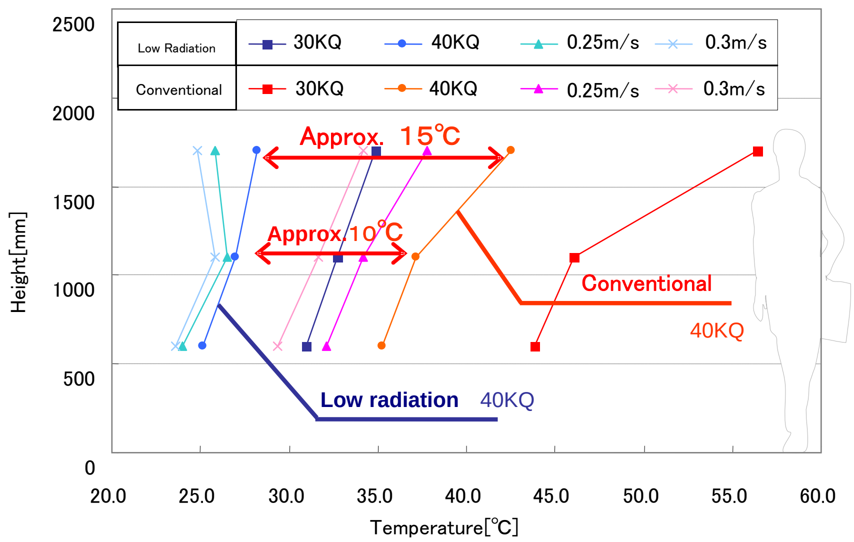
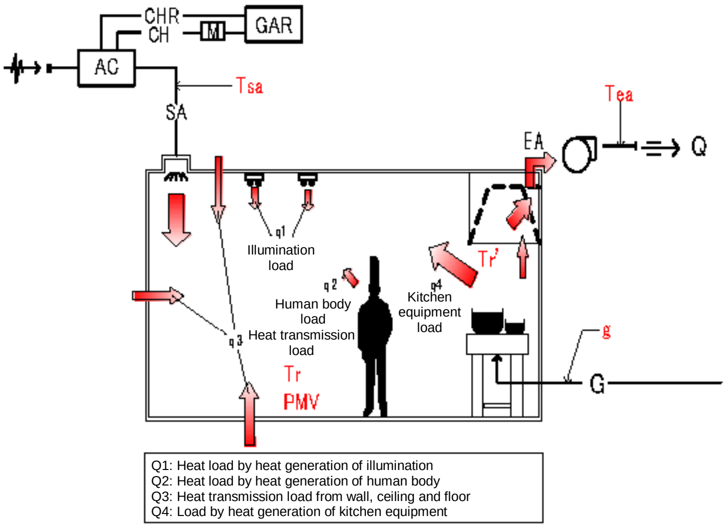


Figure 3 Air temperature at room center height and 100% load



$$Q \times C_p \times (T_r - T_{SA}) = q_1 + q_2 + q_3 + q_4$$ (When kitchen equipment is operated) -----①

$$Q \times C_p \times (T_r - T_{SA}) = q_1 + q_2 + q_3'$$ (When kitchen equipment is not operated) -----②

$$X = \frac{① - ②}{g}$$

- x : Load conversion ratio (%)
- q_1 : Illumination load
- q_2 : Human body load
- q_3 : Heat transmission load when kitchen equipment is operated (Heat transmission from floor is not taken into consideration this time)
- q_3' : Heat transmission load when kitchen equipment is not operated
- q_4 : Kitchen equipment load
- Q : Exhaust wind volume [CMH]
- g : Gas consuming quantity [m^3/h]
- T_{SA} : Supply air temperature [°C]
- T_r : Steady room temperature [°C]

Figure 4 Calculating equation of load conversion ratio

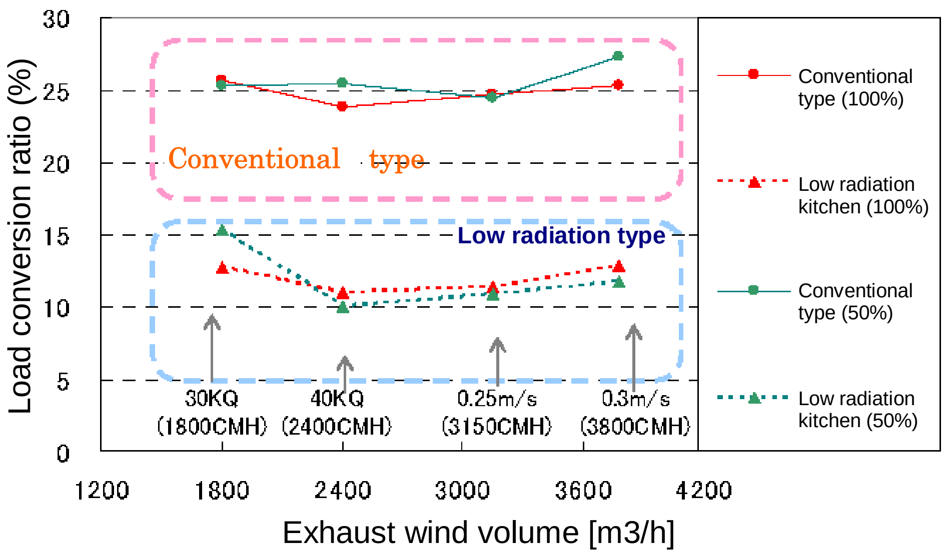


Figure 5 Load conversion ratio calculation result

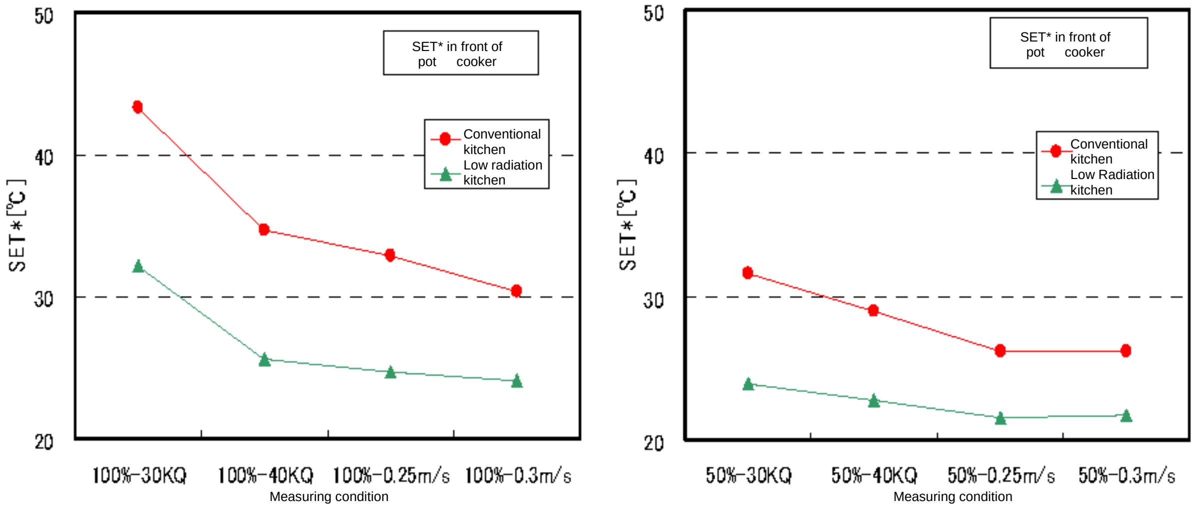


Figure 6 Distribution of ventilation air volume and SET*

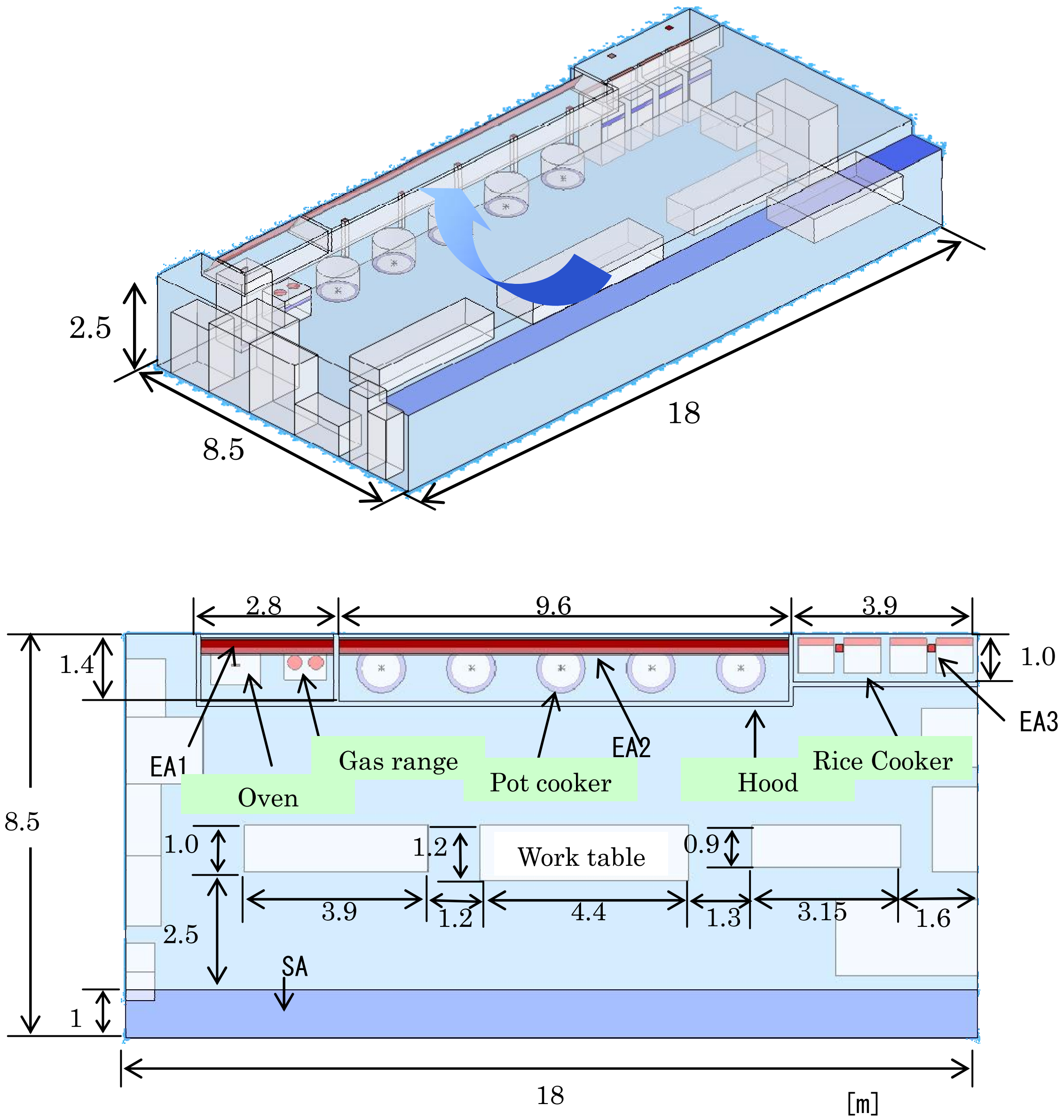
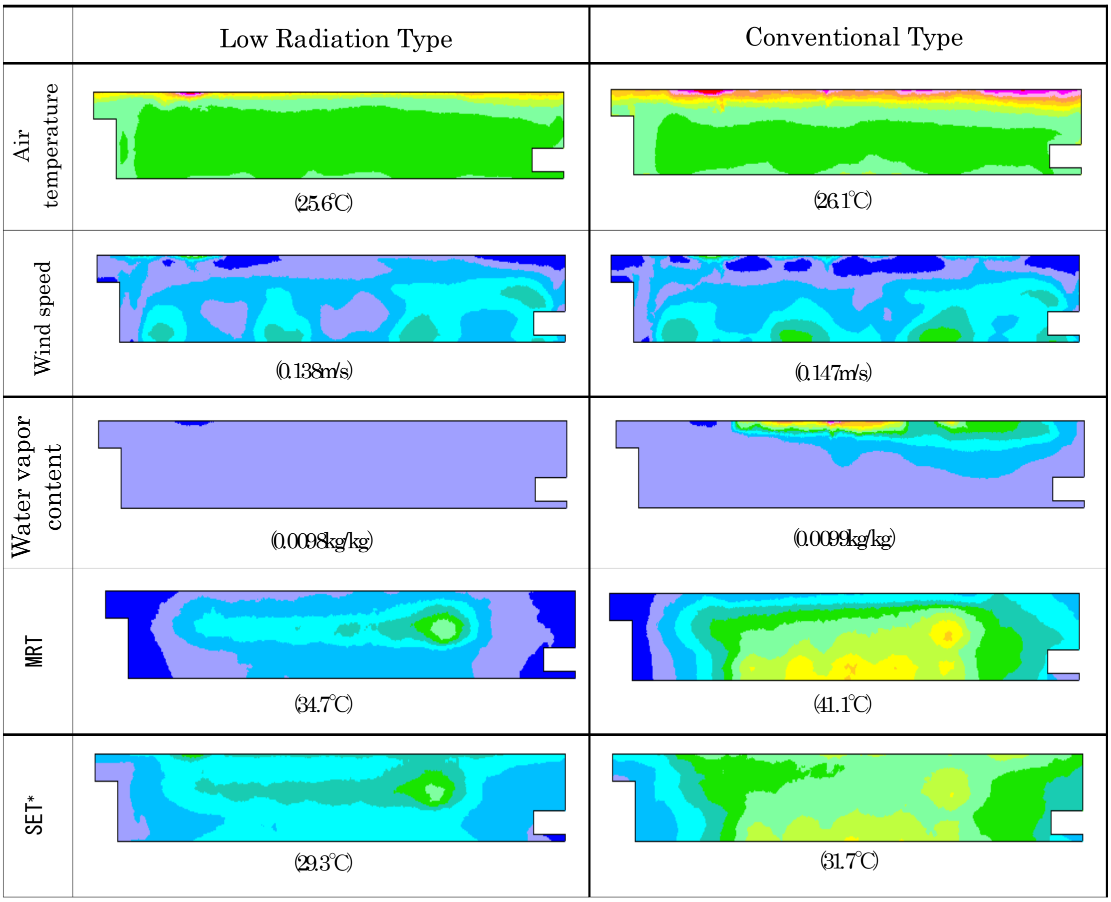


Figure 7 Commercial kitchen in a school (SA: Supply Air, EA: Exhaust Air)



NOTE: MRT and SET* are the mean radiant temperature and the standard new effective temperature, respectively. Numbers in parentheses are the average in the workspace.

Figure 8 Indices in the kitchen at vertical section 0.5 m from the front side of equipment

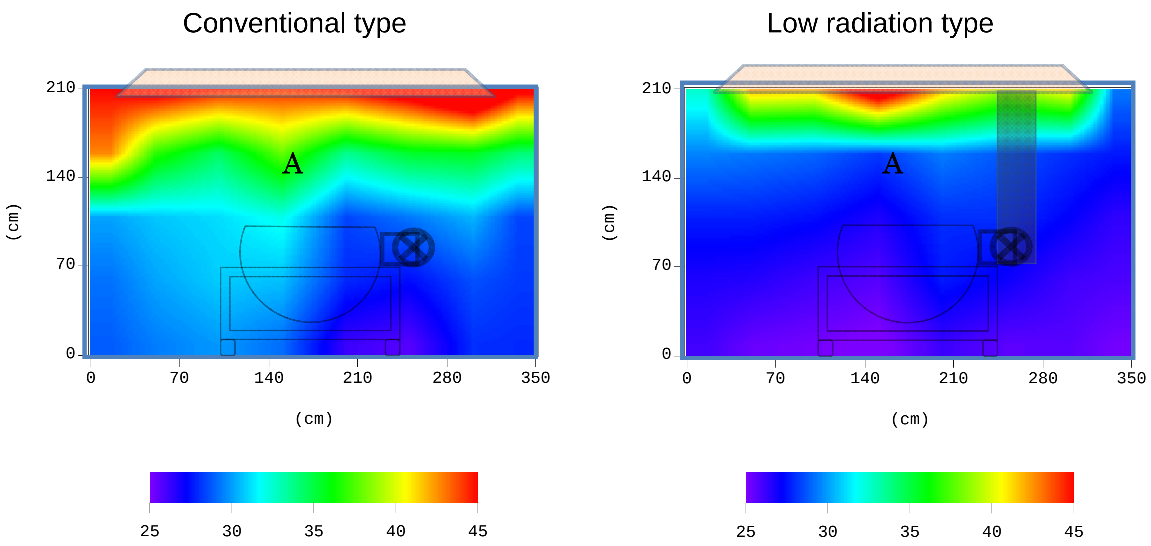


Figure 9 Temperature distributions in front of pot cooker

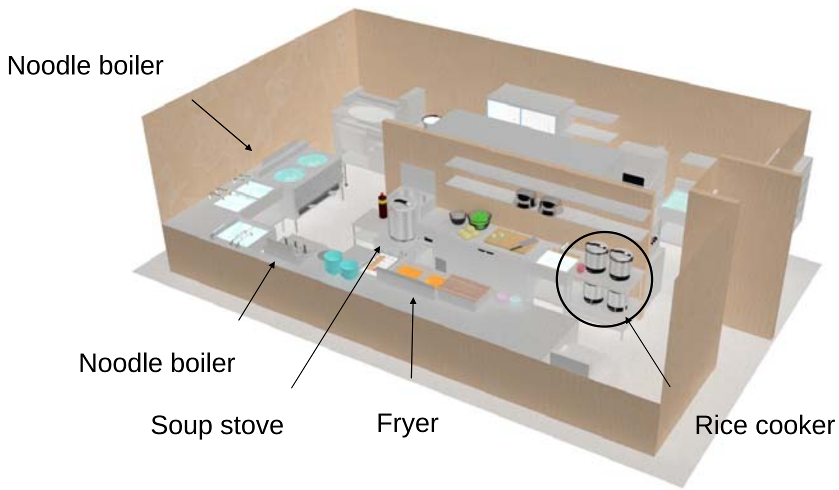


Figure 10 Schematic diagram of the kitchen for CFD analysis

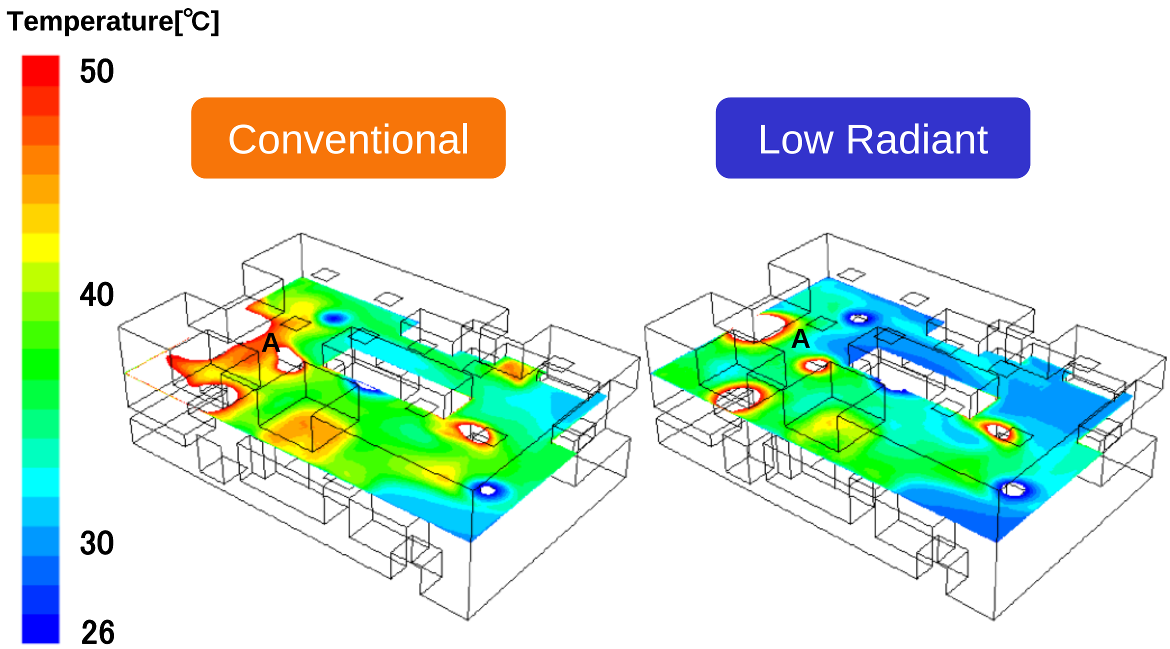


Figure 11 Results of CFD analysis