Industrial Health 2011, **49**, 605–613 **Original Article**

The Effects of Work Environments on Thermal Strain on Workers in Commercial Kitchens

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Received April 13, 2010 and accepted May 2, 2011
Published online in J-STAGE August 1, 2011

Abstract: The purpose of this study was to clarify the effect of working environments of different kinds of commercial kitchens on the thermal strain of kitchen workers. This study design was cross-sectional study, and data collection was performed during busy time in commercial kitchen from August to September 2006. The research subjects were 8 institutions, involving 7 cookers, and 16 men. Measured environmental variables were air temperature, radiant heat index, wet bulb globe thermometer index (WBGT) in front of the cookers, ambient temperature, and estimated ambient WBGT around the workers. The thermal strain on workers was evaluated by fluid loss, body temperatures, heart rate and amount of physical activity (METs). All average estimated ambient WBGTs in front of cookers were less than 27.5°C. The average heart rate was 107 ± 10 bpm, and average METs was 2.0 ± 0.6. The peak values of upper arm skin temperature and auditory canal temperature were less than 37.5°C. The work environments were affected by the kitchen spaces, cooling devices, heating methods, and heat sources. Even in the midsummer, if environmental temperatures were controlled adequately, estimated ambient WBGTs around workers were below the occupational exposure limit. Work environments and thermal strain on workers in commercial kitchen were not severe.

Key words: Commercial kitchen, Heat stress, Work environment, Thermal strain, WBGT

Introduction

Labour shortages are a major problem for the food industry in advanced countries[1)] as has been reported in countries like Japan[2)], and Canada[3)]. In particular, dependence on part-timers is high in the food service industry in Japan, and this shortage is the highest among major industries[2)]. The work environment of the food service industry is considered to be severe due to working and standing in a hot environment, in addition to irregular working hours[4–8)]. Previous studies reported that the commercial kitchen work is performed under high ambient temperatures[9–12)].

In recent years, improvements to commercial kitchen environments due to the introduction of electric cookers with high energy efficiency has also been reported in Japan[13)]. Because the electric kitchen has few radiant heat effects, a comfortable work environment has been easily established in experimental conditions[14–17)], but there have been few studies in field research, except primary schools. Concerning thermal strain, some studies have examined the heart rate during kitchen work[18, 19)], but few have examined the commercial

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kitchen environment. In commercial kitchens, no studies have compared the heat environments of electric and gas kitchens. Furthermore, although WBGT (wet bulb globe thermometer index) is the international index used to evaluate the heat environment[20], few studies have assessed kitchen environments using WBGT. In addition, many studies have measured kitchen temperatures at fixed points[4–7, 12, 13], but there have been few evaluations of the ambient temperature of workers.

Therefore, the purposes of this study were to measure the environmental parameters of kitchens and thermal strains on workers in commercial kitchens simultaneously, and to investigate the relationship between them.

Subjects and Methods

The study design was cross-sectional study consisted of 16 workers including 4 obese, and 3 overweight workers, in 8 commercial institutions, consisting of large-scale kitchens in primary schools and hospitals and small-scale kitchens in pubs and family restaurants. Four institutions had electric kitchens and the others had gas kitchens. The study was performed from August to September 2006 during the peak time of operation. Electric and gas kitchens in pubs and family restaurants of the same companies were used in order to control for working spaces and cooking implements but also menus and cooking methods.

This study was approved by The Ethics Committee of Dokkyo Medical University and complied with the Helsinki Declaration. All subjects were fully informed of the purpose, procedures and possible risks of the study, and then gave written informed consent.

Kitchen environments

As for kitchen environments, outdoor temperature, air temperature, black-globe temperature and WBGT in front of cookers were measured using a Portable PMV instrument (Kyoto Electrics Manufacturing Co. Ltd., AM-101). Because AM-101 is not fixed measuring instrument, it is useful to measure commercial kitchen environment during the peak time of operation. The cookers were grills, ovens, hot plates, fryers, kettles, pasta boiler, and cooking stoves. We directed the measuring instrument at cookers and measured consecutively every minute while maintaining a relative position at the worker's side. We measured the ambient temperature of workers using a thermal data logger (T and D Co. Ltd., TR-52) consecutively. The temperature sensor, which was covered by metal cover to protect from radiant heat, was placed on the shoulder of the worker and measured the ambient worker's temperature every 30 s. Outdoors' air temperatures and humidity were measured using an air temperature-humidity data logger (T and D Co. Ltd., TR-72U) consecutively every 30 s. The measuring instrument was fixed at a point in the outer wall of kitchen that wasn't affected by sunlight, rain, wind or exhaust from the kitchen. We measured outdoor temperatures and humidity levels consecutively for 48 h from the day before measurement to the final day of the study from August to September. The radiant heat index was assessed by subtracting air temperatures from black-globe temperatures. Moreover, we calculated the correlation coefficients and regression equations of air temperatures and WBGTs in front of cookers. Worker's ambient WBGT was estimated from a regression equation of WBGT and air temperature, and worker's ambient temperature in front of a cooker. We used the estimated ambient WBGTs in front of cookers to evaluate the heat stress of workers, because cooking workers are exposed to maximal heat stress in the kitchen. If workers used several cookers, we used the time-weighted average estimated ambient WBGTs for each worker. And this was compared to the occupational exposure limit[16] during operation. The estimated ambient WBGTs and thermal strains were measured at the same time.

Thermal strains

The subjects were 16 men (32.8 ± 5.8 yr, 171.6 ± 5.5 cm) accustomed to the heat stress of these kitchen environments as full-time workers. Six were electric kitchen workers, and the other 10 were gas kitchen workers. We measured the thermal strains during single meal preparation at the peak time (187 ± 77 min, 69–352 min), there were multiple observation periods for a single person's variable tasks. For the thermal strain on workers, fluid loss, heart rate, amount of activity (Metabolic Equivalent, METs), and body temperatures (upper arm skin temperature and auditory canal temperature) were measured every 5 s. We used average values of each thermal strains, because each workers engaged variable tasks. Table 1 shows subjects' age, height, body weight and BMI. The subjects were weighed using a digital scale (FG-150KBM, A&D Company) before and after measurement, wearing only underwear. Fluid loss assessed the difference of before weight and after weight, with added water intake.

The amount of activity was estimated using a wrist accelerometer, ACTICAL ACTIVITY MONITOR (MINIMITTER Co., Ltd.). Heart rate was estimated using ACTIHR (MINIMITTER Co., Ltd.). After measurement we downloaded these data to a computer using dedicated software and analyzed them. The ACTICAL ACTIVITY MONITOR calculated the momentum using the appropriate algorithm of this system by the accelera-

Table 1. Subjects' age, height and body weight

Institution	Heat source	No	Age	Height	Body weight[1)]	BMI
			yr	cm	kg	
Large-scale kitchen						
Primary school	Electric	1	27	170	57.6	19.9
		2	35	176	88.7	28.6
	Gas	3	35	160	59.6	23.3
		4	42	170	69.2	23.9
Hospital	Electric	5	32	177	73.3	23.4
		6	34	164	63.9	23.8
	Gas	7	45	170	91.7	31.7
		8	34	164	63.7	23.7
		9	35	170	80.4	27.8
Small-scale kitchen						
Pub	Electric	10	28	181	104.0	31.7
	Gas	11	31	170	64.1	22.2
		12	31	170	64.6	22.4
Family restaurant	Electric	13	32	165	81.4	29.9
		14	23	178	54.3	17.2
	Gas	15	32	175	93.4	30.5
		16	32	175	92.7	30.3

[1)]Body weight before measurement, wearing only underwear.

tion reaction of the wrist every 15 s, and the heart rate was measured every minute. Averages of these values were used in this study.

Upper arm skin temperature was measured 10.0 cm above the right wrist, and was measured using surface-type probes (Nikkiso YSI Co., Ltd.). In addition, an inflatable sensor for auditory canal temperature measurement (Nikkiso YSI Co., Ltd.) was inserted into the ear and held in place with medical tape.

We classified the work into heat cooker proximity work (bake, boil, steam, sauté, and fry) and non-heat cooker proximity work (cut, dish, wash, carry and so on) by 30 s interval snap-reading method. The relationship between the work environments and physiological conditions of the workers were investigated according to the type of work.

Statistical analysis

We estimated the relationship between kitchen environments and thermal strains. To compare electric and gas kitchens, Student's non-paired *t*-test, ANOVA, and Bonferroni multiple analyses were used. We used Pearson's correlation coefficients to assess the relationship of two variables. Analysis was performed using SPSS.Ver15.0 (Japan SPSS, Tokyo). In the two-sided test, $p<0.05$ was considered significant.

Results

Characteristics of the institutions and the outdoor air temperatures

As shown in Table 2, the kitchen area and numbers of meals produced in primary schools and hospitals, which were large-scale kitchens, were more than in pubs and family restaurants, which were small-scale kitchens. Except for pubs, the gas kitchens were older than the electric kitchens. Air conditioners were present in all institutions, except for the primary school gas kitchen. In pubs and family restaurants, spot coolers were installed. The outdoor temperatures were significantly different between measurement days.

Air temperatures, radiant heat indexes and WBGTs in front of cookers

As shown in Table 3, in the large-scale kitchens, air temperatures, radiant heat indexes and WBGTs in front of gas cookers were higher than those of electric cookers. On the other hand, in pubs, the three temperatures in the electric kitchen were higher than in the gas kitchen. In family restaurants, the three temperatures differed according to the cooker. As for the radiant heat index, there were no differences by the heat sources of ovens and fryers in pubs, but the other cookers in gas kitchens were significantly higher than those of electric

Table 2. Characteristics of the institutions and the outdoor air temperatures

	Heat source	Completion yr	Meal production	Institution		Cooling devices		Outdoor temperature, °C			
			meals/day	space, m^2	height, m	air-conditioner	spot cooler	n	mean	SD	*p*-value[1)]
Large-scale kitchen											
Primary school	Electricity	2006	960	282	2.5	Yes	No	559	22.1	± 2.6	0.001
	Gas	1986	520	200	3.5	No	No	400	26.5	± 1.4	
Hospital	Electricity	2003	600	160	2.8	Yes	No	348	26.1	± 0.6	0.001
	Gas	1974	2,640	816	2.5	Yes	No	373	22.2	± 1.0	
Small-scale kitchen											
Pub	Electricity	2006	50	42	2.2	Yes	Yes	275	18.0	± 1.1	0.001
	Gas	2006	120	44	2.4	Yes	Yes	195	19.0	± 0.1	
Family restaurant	Electricity	2003	420	71	2.4	Yes	Yes	240	25.5	± 0.6	0.001
	Gas	1976	480	83	2.7	Yes	Yes	240	21.5	± 0.6	

[1)]Student's non-paired *t*-test.

Table 3. Air temperatures, radiant heat indexes and WBGTs of the cookers

	Cooker	Air temperature, °C: Electric kitchen n	mean ± SD	Gas kitchen n	mean ± SD	*p*-value[1)]	Radiant heat index: Electric kitchen mean ± SD	Gas kitchen mean ± SD	*p*-value[1)]	WBGT, °C: Electric kitchen mean ± SD	Gas kitchen mean ± SD	*p*-value[1)]
Large-scale kitchen												
Elementary school	Kettle	239	23.8 ± 1.0	166	29.5 ± 3.5	0.001	0.72 ± 0.60	2.30 ± 2.11	0.001	21.1 ± 0.9	24.3 ± 2.6	0.001
	Oven	44	27.6 ± 3.4	29	34.4 ± 6.5	0.001	3.97 ± 2.23	3.06 ± 1.98	n.s.	24.5 ± 2.0	27.4 ± 4.3	0.001
Hospital	Kettle	273	21.2 ± 0.6	98	31.9 ± 1.7	0.001	0.95 ± 0.42	1.73 ± 0.97	0.001	19.3 ± 0.6	25.1 ± 1.2	0.001
	Cooking stove	279	21.7 ± 0.5	68	31.2 ± 1.5	0.001	0.81 ± 0.39	2.29 ± 1.19	0.001	19.9 ± 0.5	24.6 ± 1.2	0.001
Small-scale kitchen												
Pub	Cooking stove	23	29.8 ± 1.5	46	28.3 ± 1.8	0.001	5.83 ± 1.45	2.85 ± 1.95	0.001	23.9 ± 1.0	22.9 ± 1.7	0.001
	Grill	59	35.6 ± 6.5	71	32.2 ± 3.3	0.001	8.38 ± 3.23	10.82 ± 3.50	0.001	28.7 ± 4.6	27.3 ± 3.2	n.s.
	Fryer	33	30.0 ± 0.6	70	29.1 ± 1.8	0.001	3.69 ± 0.63	3.04 ± 2.69	n.s.	24.4 ± 0.5	23.0 ± 1.8	0.010
Family restaurant	Cooking stove	55	27.3 ± 0.9	53	29.6 ± 1.4	0.001	3.75 ± 0.84	5.64 ± 1.79	0.001	22.7 ± 0.8	25.3 ± 0.6	0.001
	Hot plate	77	29.2 ± 1.3	131	29.2 ± 1.3	n.s.	3.93 ± 1.22	5.05 ± 1.16	0.001	23.7 ± 1.3	24.9 ± 0.7	0.001
	Fryer	44	27.2 ± 0.9	20	26.1 ± 0.5	0.001	3.20 ± 0.95	2.77 ± 0.60	0.050	23.0 ± 1.5	22.8 ± 0.4	0.001
	Oven	54	29.4 ± 1.0	17	30.5 ± 0.4	0.001	2.86 ± 1.11	3.65 ± 0.87	n.s.	23.4 ± 0.7	24.5 ± 0.3	0.001
	Pasta boiler	35	26.8 ± 1.0	7	32.0 ± 0.5	0.001	2.08 ± 0.88	3.10 ± 0.72	0.001	22.5 ± 1.1	26.2 ± 0.3	0.001

[1)]Student's non-paired *t*-test.

kitchens. In both gas and electric kitchens, the radiant heat indexes of the grills in pubs were higher than those of the other cookers. WBGTs in front of the cookers showed almost identical air temperatures.

Relationship between air temperatures and WBGTs in front of cookers

As shown in Table 4, except for the gas kitchen cooking stove in the family restaurant, a highly significant correlation was found in the relationship between WBGTs and air temperatures. We obtained the regression equation between air temperatures and WBGTs, y means WBGT and x means air temperature in front of cooker.

Worker's ambient air temperatures and estimated ambient WBGTs in front of cookers

As shown in Table 5, worker's ambient temperatures in front of gas cookers were significantly higher than electric cookers. All average estimated ambient WBGTs in front of cookers were less than 27.5°C. Estimated ambient WBGTs in front of gas cookers in primary schools and hospitals were higher than electric cookers. The estimated ambient WBGTs in front of the gas stove were higher than in front of electric stove in family restaurant kitchens, though the estimated differences in ambient WBGTs in front of all other cookers were not statistically significant between gas and electric.

Cooker proximity rate, thermal strains, and amount of activities

As shown in Table 6, the average cooker proximity

Table 4. Relationship between air temperature and WBGTs of the cookers

	Cooker	Heat source	n	r[1)]	*p*-value	Regression equation of Air temperature (x) and WBGT (y)
Large-scale kitchen						
Elementary school	Kettle	Electricity	239	0.342	0.001	y=0.30x+13.90
		Gas	166	0.970	0.001	y=0.72x+3.04
	Oven	Electricity	44	0.953	0.001	y=0.55x+9.31
		Gas	29	0.980	0.001	y=0.64x+5.37
Hospital	Kettle	Electricity	273	0.893	0.001	y=0.95x–0.91
		Gas	98	0.806	0.001	y=0.57x+7.02
	Cooking stove	Electricity	279	0.880	0.001	y=0.87x+0.88
		Gas	68	0.849	0.001	y=0.65x+4.50
Small-scale kitchen						
Pub	Cooking stove	Electricity	23	0.948	0.001	y=0.64x+4.96
		Gas	46	0.924	0.001	y=0.89x–2.20
	Grill	Electricity	59	0.989	0.001	y=0.71x+3.59
		Gas	71	0.982	0.001	y=0.96x–3.37
	Fryer	Electricity	33	0.790	0.001	y=0.71x+3.01
		Gas	70	0.908	0.001	y=0.90x–3.26
Family restaurant	Cooking stove	Electricity	37	0.764	0.001	y=0.75x+2.73
		Gas	53	0.233	n.s.	y=0.11x+22.13
	Hot plate	Electricity	77	0.734	0.001	y=0.72x+3.14
		Gas	131	0.328	0.001	y=0.17x+19.98
	Fryer	Electricity	35	0.966	0.001	y=0.90x–1.59
		Gas	20	0.848	0.001	y=0.63x+6.50
	Oven	Electricity	54	0.912	0.010	y=0.83x - 1.16
		Gas	17	0.645	0.001	y=0.53x+8.39
	Pasta boiler	Electricity	35	0.682	0.001	y=0.80x+0.75
		Gas	7	0.852	0.001	y=0.49x+10.57

[1)]Pearson's correlation coefficients.
y: WBGT, x: Air temperature.

rate was 25.0% (6.3–46.7%) during operation, and different among workers. The ambient temperatures of gas kitchen workers were significantly higher than those of electric kitchen workers. Average fluid loss per hour was 0.30 ± 0.11 kg/h (0.11–0.45 kg/h). Average heart rate was 107 ± 10 bpm (88–124 bpm), and the average amount of activity was 2.0 ± 0.6 METs (1.0–2.9 METs).

As shown in Fig. 1, there was a significant correlation between the ambient temperatures of workers and fluid loss per hour (n=16, r=0.504, $p<0.05$). Although there was a significant correlation between the ambient temperatures of workers and upper arm skin temperatures (n=14, r=0.763, $p<0.01$), no significant correlation was shown between the ambient temperatures of workers and auditory canal temperatures (n=12, r=0.473, $p=0.880$). Although there was a moderate correlation between the cooker proximity rate and the ambient temperature (n=16, r=0.518, $p=0.058$), no significant correlation was shown between the cooker proximity rate and upper arm skin temperatures (n=14, r=0.486, $p=0.078$), and auditory canal temperatures (n=12, r=0.056, $p=0.850$).

Discussion

This is the first study to examine the relationship between the various commercial kitchen environments and thermal strains on workers during peak time operation. In this study, we found that heat stress exposures in commercial kitchens are not likely to above the occupational exposure limit even in the midsummer. Though fluid loss and the upper arm skin temperature were influenced by the ambient temperatures of workers, the physiological strain was in the acceptable range.

This study showed the following two strengths: first, we used the estimated ambient WBGTs to evaluate the thermal strain on kitchen workers in comparison to the occupational heat stress exposure limit[16]. So, we measured three kinds of temperatures, air temperature, black-globe temperature and WBGT simultaneously in the same place. And we calculated the estimated ambient WBGT using the regression equations of WBGTs and air temperatures, and the workers' ambient temperatures. WBGT is the international index for evaluating heat environments, which is reflected in air tempera-

Table 5. Workers' ambient air temperatures and estimated ambient WBGTs in front of cookers

	Cooker	Heat source	Workers' ambient air temperatures, °C					Estimated ambient WBGTs[1)], °C			
			n	min.	max.	mean SD	p-value[2)]	min.	max.	mean SD	p-value[2)]
Large-scale kitchen											
Primary school	Kettle	Electricity	186	23.6	30.1	25.8 ± 1.2	0.001	21.0	29.9	22.5 ± 2.0	0.001
		Gas	292	28.6	39.9	33.9 ± 2.4		23.7	31.8	27.5 ± 1.7	
	Oven	Electricity	21	25.3	33.1	28.2 ± 1.8	0.001	21.0	21.8	21.3 ± 0.2	0.001
		Gas	14	32.4	38.3	35.6 ± 1.6		21.4	21.7	21.6 ± 0.2	
Large-scale kitchen											
Hospital	Kettle	Electricity[3)] Gas	153	26.3	33.1	30.0 ± 1.9		22.7	31.7	24.8 ± 1.5	
	Cooking stove	Electricity	20	22.4	26.4	23.9 ± 1.1	0.001	21.9	23.0	22.5 ± 0.3	0.001
		Gas	157	28.7	42.1	31.5 ± 2.1		22.7	24.9	24.1 ± 0.6	
Small-scale kitchen											
Pub	Cooking stove	Electricity[3)] Gas	20	25.7	30.1	28.1 ± 1.3		20.6	24.5	22.7 ± 1.2	
	Grill	Electricity	12	26.0	28.3	27.1 ± 0.8	0.001	23.2	33.6	26.9 ± 3.6	n.s.
		Gas	32	29.1	41.7	32.0 ± 2.7		21.9	32.0	25.3 ± 2.2	
	Fryer	Electricity[3)] Gas	26	27.8	40.8	31.2 ± 3.3		21.9	36.4	25.4 ± 3.4	
Small-scale kitchen											
Family restaurant	Cooking stove	Electricity	76	23.1	32.9	28.1 ± 1.4	0.001	22.5	28.3	25.3 ± 1.2	0.032
		Gas	61	26.5	36.3	31.7 ± 2.6		24.2	28.3	25.8 ± 1.1	
	Hot plate	Electricity	199	25.9	35.3	28.7 ± 1.6	0.001	20.1	28.7	23.9 ± 1.3	n.s.
		Gas	63	28.5	35.8	32.1 ± 1.6		22.5	26.6	23.9 ± 0.8	
	Oven	Electricity	15	25.7	31.4	28.2 ± 1.4	0.007	22.8	25.3	23.9 ± 0.9	n.s.
		Gas	9	26.5	37.8	33.8 ± 4.7		22.3	24.8	23.6 ± 0.8	
	Pasta boiler	Electricity	2	27.2	27.5	27.4 ± 0.2	0.050	23.0	23.0	23.0 ± 0.1	n.s.
		Gas	14	28.2	36.4	33.0 ± 2.9		22.3	24.0	23.0 ± 0.8	

1) Estimated ambient WBGTs were calculated from a regression equation of WBGT and air temperature, and worker's ambient temperature in front of cookers, to compare the occupational exposure limit.
2) Student's non-paired t-test.
3) There were no operations.

Table 6. Cooker proximity time, thermal strains and amount of activities during operation

subject			Cooker proximity time[2)]			Workers' ambient temperature °C			Fluid loss		Upper arm skin temperature, °C			Auditory canal temperature, °C			Heart rate, bpm			Amount of activity, METs		
			n	min	%[3)]	mean SD	p-value[4)]	p-value[5)]	kg	kg/h	min	max	mean SD	min	max	mean SD	min	max	mean SD	min	max	mean SD
Large-scale kitchen																						
1	Primary school	Electric kitchen	271	74	27.3	25.2 ± 1.2	0.001	1–3,4	0.48	0.11	27.6	34.1	30.5 ± 1.4	35.5	36.2	35.9 ± 0.2	84	189	107 ± 26	1.0	2.8	1.4 ± 0.4
2			279	51	18.3	25.3 ± 0.9		2–3,4	1.60	0.34	27.3	33.6	31.2 ± 1.5	36.1	36.5	36.3 ± 0.1	84	118	102 ± 5	1.0	3.3	1.9 ± 0.6
3		Gas kitchen	169	79	46.7	31.1 ± 3.0		3–1,2,4	0.54	0.19	32.4	35.9	34.0 ± 1.1	36.3	37.5	36.9 ± 0.4	69	158	91 ± 17	1.0	2.4	1.4 ± 0.3
4			229	58	25.3	30.4 ± 3.1		4–1,2,3	1.02	0.27	31.7	37.3	34.6 ± 1.6	36.3	37.4	36.9 ± 0.4	74	183	113 ± 32	1.0	3.3	1.6 ± 0.5
5	Hospital	Electric kitchen	345	68	19.7	23.6 ± 1.4	0.001	5–6,7,8,9	0.92	0.16	30.2	35.0	32.2 ± 0.6	36.2	36.9	36.5 ± 0.1	84	144	114 ± 11	1.1	3.8	2.7 ± 0.6
6		Gas kitchen	185	42	23.0	29.8 ± 2.2		6–5,	1.40	0.45	33.0	36.2	34.9 ± 0.7	36.9	37.5	37.3 ± 1.1	108	162	120 ± 9	1.6	4.5	2.9 ± 0.7
7			190	57	30.0	29.4 ± 1.6		7–5,8	1.00	0.32	33.3	36.7	34.9 ± 0.9	36.3	36.9	36.6 ± 1.1	76	177	101 ± 24	1.0	4.4	2.0 ± 1.2
8			188	39	20.7	30.2 ± 1.2		8–5,7,8	0.94	0.30	29.6	34.4	32.7 ± 1.2	36.3	36.8	36.6 ± 1.1	74	180	103 ± 27	1.0	4.2	2.0 ± 0.6
9			197	47	23.9	29.4 ± 1.5		9–5,8	1.20	0.37	32.1	37.0	34.6 ± 1.6	—	—	— —	106	150	124 ± 10	1.5	3.8	2.9 ± 0.7
Small-scale kitchen																						
10	Pub	Electric kitchen	126	8	6.3	27.3 ± 1.5	0.001	10–12	0.66	0.31	30.1	34.5	32.3 ± 1.0	36.9	37.1	37.0 ± 0.1	93	165	116 ± 16	1.0	2.2	1.3 ± 0.2
11		Gas kitchen	75	8	10.7	26.8 ± 2.1		11–12	0.14	0.11	29.2	33.2	30.4 ± 0.7	36.1	36.7	36.2 ± 1.3	92	176	107 ± 18	1.5	4.4	2.4 ± 0.6
12			68	21	30.9	30.0 ± 2.9		12–10,11	0.30	0.26	33.3	34.5	33.8 ± 0.3	36.7	37.0	36.8 ± 0.1	93	165	113 ± 28	1.3	4.1	1.8 ± 0.7
13	Family restaurant	Electric kitchen	126	22	17.5	27.9 ± 1.1	0.001	13–15,16	0.86	0.41	—	—	— —	—	—	— —	—	—	— —	—	—	— —
14			150	53	35.3	28.3 ± 1.5		14–15,16	0.90	0.36	—	—	— —	—	—	— —	—	—	— —	—	—	— —
15		Gas kitchen	116	25	21.6	31.3 ± 2.7		15–13,14	0.82	0.42	32.4	35.8	33.8 ± 0.9	—	—	— —	75	106	88 ± 5	1.1	2.9	1.9 ± 0.4
16			119	51	42.9	31.1 ± 2.8		16–13,14	0.86	0.43	32.2	35.2	34.0 ± 0.8	35.6	36.7	36.2 ± 0.2	80	112	98 ± 7	1.1	3.6	2.3 ± 0.5

—: missing data
1) Student's non-paired t-test.
2) cooker proximity time: working time (bake, boil, steam, saute and so on) using cooking equipment.
3) %: cooker proximity time / total occupational time.
4) ANOVA
5) Bonferroni multiple analysis: $p<0.05$.

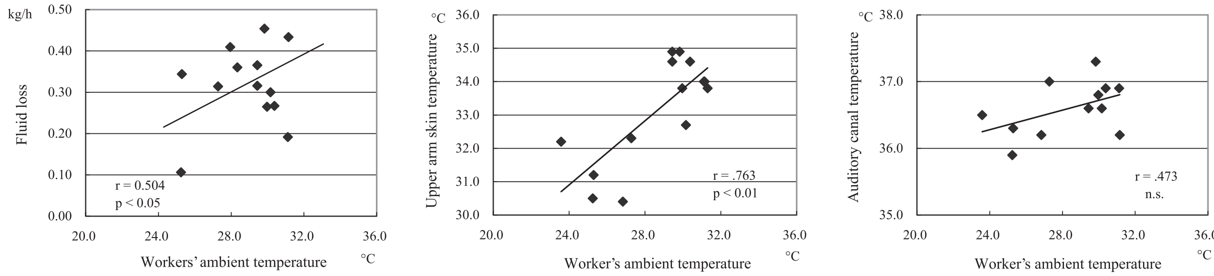

Fig. 1. The relationship between workers' ambient temperatures and fluid loss and body temperature with Peason's correlation coefficients.

ture, radiant heat, humidity and air velocity[20]. The kitchen is an environment wherein workers are exposed not only to heat from heating equipment but also from high humidity stemming for water usage, and air-flow from cooling devices. Therefore, it is desirable to use WBGT rather than evaluating temperature and humidity separately to evaluate kitchen environment accurately.

The second strength was that we measured the workers' ambient temperatures and thermal strains in different type of commercial kitchens simultaneously during peak time of operation in the midsummer. Various studies have measured the thermal strains of workers in heat environments, such as steel[21], coal mine[22, 23] and construction[24], but the thermometric methods were poor. We also measured the ambient temperatures at the shoulder where workers felt hot.

This study's weakness was the difficulty to compare thermal strains, because the cooker proximity rate differed among workers. Because the physiological responses were differed individual, the heart rate and body temperature could not be compared among workers.

Though previous studies reported that the commercial kitchen work is performed under high ambient temperatures[9–12], this study showed that heat stress in commercial kitchens was not likely to be above the occupational exposure limit by evaluating average estimated ambient WBGTs in front of cookers. In other words WBGTs in front of cookers do not accurately indicate workers' ambient temperatures, as through regular rest, self-pacing and movement away from heat sources, workers can avoid heat stress[25].

We used the average thermal strains and worker's ambient temperature from start to finish as 1 work unit, because workers engaged in several different tasks in a short period of time. We measured the body temperature every 5 s, and heart rate, METs and worker's ambient temperature every 30 s during busy time in commercial kitchens. Especially with small-scale kitchens, it was difficult to distinguish brief tasks from each other.

No previous reports on commercial kitchens measured the ambient temperatures of workers consecutively. The ambient temperature and upper arm skin temperature of workers were significantly correlated. Our results confirmed the previous study that skin temperature rose when ambient temperature increased[26]. No correlation was found between the ambient temperature and auditory canal temperature, though a potential problem with our measurements is that sensor readings may have been affected by subjects' proximity to cooling devices.

Because total circulating blood volume increases, the heart rate increases under heat stress[25, 28]. In previous studies, the relationships between WBGT and heart rate under the heat environment were reported; in glass bangle workers, the heart rate was 89 bpm (WBGT 35.2°C)[27], in steel plate workers, the heart rate was 150 bpm (WBGT 33.2°C)[21]. The ACGIH guidelines for thermal stress state that work should stop if the prolonged heart rate is over 160 bpm at younger than 35 yr old and over 140 bpm at or older than 40 yr old[29]. In our result, heart rates were not high compared with previous studies. On the other hand, the average amount of activity was 1.0–2.9 METs in this study. Although there is no report on the amount of activity in commercial kitchen work, the amount of activity in home cooking, washing dishes, and transporting dishes is 2.0, 2.3 and 2.5 METs, respectively[30]. Our results consisted with the previous study.

The occupational heat stress exposure limit was defined according to amount of activity[9, 16]. U.S. Department of Labour uses the occupational exposure WBGT limit of 29.4°C in the case of a moderate work load (50% work, 50% rest)[9]. Japanese occupational exposure limit is WBGT 30.5°C and 29.0°C respectively for light and moderate workload. In the worksites under investigation here, physical activities were light or moderate, so heat stress exposures in commercial kitchens were not likely to be above the occupational exposure limit.

In this study, although there were wide ranges of METs, tasks generating subject's METs peak value were moving or lifting tasks with heavy loads, not tasks in front of cookers. So we considered heat stress as not severe during high physical activity. On the other hand, except for kettle use, work in front of cookers was performed in a fixed standing position and involved only the upper limbs, so METs generated during cooking were not high. The peak values of upper arm skin temperature and auditory canal temperature were near an expected baseline for warm environments.

Commercial kitchens are the complex environments wherein air temperature, humidity, radiant heat and airflow interact. It was difficult to estimate commercial kitchen worker's thermal strain because the work environments were affected by the kitchen spaces, cooling devices, heating methods, cooker proximity time and heat sources. Although in the midsummer with a high outdoor temperature, work environment was sustained adequately. Consequently, WBGTs in front of cookers and estimated ambient WBGTs of worker were below the occupational exposure limit[31–33]. So, the thermal strains on kitchen workers were not severe. Because we included few institutions and subjects, we can not generalize these results. In the future, it is necessary to study more research sites under different conditions.

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