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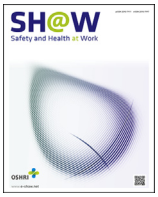

Original Article

Climate Warming and Occupational Heat and Hot Environment Standards in Thailand

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ABSTRACT

Background: During the period 2001 to 2016, the maximum temperatures in Thailand rose from 38–41°C to 42–44°C. The current occupational heat exposure standard of Thailand issued in 2006 is based on wet bulb globe temperature (WBGT) defined for three workload levels without a work–rest regimen. This study examined whether the present standard still protects most workers.
Methods: The sample comprised 168 heat acclimatized workers (90 in construction sites, 78 in foundries). Heart rate and auditory canal temperature were recorded continuously for 2 hours. Workplace WBGT, relative humidity, and wind velocity were monitored, and the participants' workloads were estimated. Heat-related symptoms and signs were collected by a questionnaire.
Results: Only 55% of the participants worked in workplaces complying with the heat standard. Of them, 79% had auditory canal temperature $\leq$ 38.5°C, compared with only 58% in noncompliant workplaces. 18% and 43% of the workers in compliant and noncompliant workplaces, respectively, had symptoms from heat stress, the trend being similar across all workload levels. An increase of one degree (C) in WBGT was associated with a 1.85-fold increase (95% confidence interval: 1.44–2.48) in odds for having symptoms.
Conclusion: Compliance with the current occupational heat standard protects 4/5 of the workers, whereas noncompliance reduces this proportion to one half. The reasons for noncompliance include the gaps and ambiguities in the law. The law should specify work/rest schedules; outdoor work should be identified as an occupational heat hazard; and the staff should include occupational personnel to manage heat stress in establishments involving heat exposure.

1. Introduction

Thailand is located in South East Asia (SEA) in the tropical climatic zone where weather is hot and humid for the most part of the year and causes heat hazards especially in outdoor work and workplaces with hot processes. Furthermore, SEA is the region most vulnerable to climate warming because of greenhouse gas emissions, the aftermath of advancing economic development and population growth. During the period 2001 to 2016, the mean maximum temperatures in Thailand rose from 38–41°C to 42–44°C, with relatively small differences between areas [1,2].

The first Thai occupational exposure to heat and hot environment standard to protect workers was issued in 1976 [3] and revised in 2006. This standard used wet bulb globe temperature (WBGT) as an index to estimate heat stress in hot working environments. However, the WBGT limits and related workload levels are country specific. Some countries belonging to the same tropical zone, e.g., Malaysia [4] and Singapore [5], adopted the threshold limit values (TLVs) issued by the American Conference of Governmental Industrial Hygienists (ACGIH) [6] as their occupational exposure to heat and hot environment standard; the Philippines use TLV values from the older version of the ACGIH [7], whereas Thailand has its own standard. In Thailand, the WBGT limits are

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defined according to workload levels, based on the studies conducted by the Ministry of Industry [8,9]. Three workload WBGT limits are used: 30°C for heavy (>350 Kcal/h), 32°C for moderate (200–350 Kcal/h), and 34°C for light (<200 Kcal/h) workloads without specifying the work/rest schedule. Later on, the Ministry of Labor announced this as the occupational exposure standard in 2006. A minor amendment was made to the law in 2016, but the WBGT limits and the workload levels remained unchanged, and the changes in climatic conditions and technology which possibly have an impact on heat stress were not taken into account.

The rising temperatures affect large numbers of outdoor workers, because out of the total of 37.1 million employed people in Thailand, 10.9 million and 2.8 million work in agriculture and in construction fields, respectively [10]. Thus, the occupational standard for heat exposure set up in 2006 may have left significant numbers of workers poorly protected. Although humans can adapt to increasing temperatures, there is evidence that an upper limit exists for acclimatization [11].

According to the Strategic and Planning Division, Ministry of Public Health, in 2016, 2,473 cases of heat illness (4.12 per 100,000 workers) occurred in Thailand in outdoor work alone, most commonly among agricultural and construction workers aged 15–60 years [12]. Most of the cases were informal workers for whom the occupational safety and health law was not strictly enforced. Furthermore, the Division of Health Promotion and Preventive Medicine, Royal Thai Army Medical Department, reported that from 2004 to 2014, 82 military recruits sustained heat illness, 22 of these dying from heat stroke because of outdoor military training [13]. During the period 2009–2015, 2,150 cases of heat illness and 22 deaths reportedly occurred in the industrial sector and were recorded under the heading “exposed to heat and hot objects” which includes working in hot environment, touching hot objects, and burns [14].

The rising temperatures due to climate change may increase occupational heat exposure among both outdoor and indoor workers. Because the current occupational heat exposure standard in Thailand may not be appropriate, workers may be at risk at sustaining heat adversities. The present study aimed to explore whether or not the present occupational heat exposure standard provides adequate protection for the workers. The study focused on construction and foundry occupational settings, which represent outdoor and indoor working conditions, respectively.

2. Materials and methods

2.1. The workplaces and the subjects studied

A number of selected construction sites and foundry plants were contacted and requested to participate in the study. Finally, 18 construction sites and 3 foundries participated. All outdoor workers in the construction sites and workers in eight selected jobs in the foundries were invited. The construction setting comprised small and medium size construction projects building 1- to 3-storey structures in north-eastern Thailand. Most work was labor intensive, and few machines were used, most of these being small machines. The majority of workers were unskilled and could be assigned several tasks during the day; however, all tasks were in the same location and unshaded environment. They worked 8 hours daily on 7 days a week. During the day, 1 hour lunch break was scheduled, but there were no scheduled shorter breaks. However, the workers could take breaks on demand as long as the daily work plan remained undisturbed.

Three large foundry plants in central Thailand producing automobile parts represent workplaces where hot work is conducted indoors. In the foundries, three 8-hour work shifts were scheduled daily, with 10-minute breaks every 2 hours in rest areas, plus 1-hour lunch break. To have reasonable numbers of participants in each workload class as defined in the occupational safety and health law of Thailand (light: <200 Kcal/h; moderate: 200–350 Kcal/h; heavy: >350 Kcal/h), the subjects were selected from the following processes: molding, coring, furnace (melting and furnace maintenance), casting, and felting shops.

The participants were recruited based on the health status and experience in the current work and working environment. The detailed eligibility criteria were (1) age 20–60 years; (2) worked in his/her current job or position for at least 2 months on the date of data collection; (3) no self-reported physician-made diagnosis of heart disease, elevated blood pressure, thyroid disease, diabetes; (4) none of the following symptoms during 24 hours preceding data collection: fever, diarrhea, unusual weakness, headache, stupor, and dizziness; (5) not taken any medicines that affect body temperature (antihistamines, salicylates, and methaqualone); and (6) consumed no alcoholic beverages during 24 hours preceding data collection.

The research proposal was reviewed and approved by the Ethics Committee on Human Rights Related to Human Experimentation, Mahidol University (No. MUPH 2015-147) before the study started in early 2016. All participants were informed that their participation is voluntary, and the data will be kept strictly confidential. Each participant signed a written consent form.

2.2. Data collection

The data were collected in summer (March to June) 2016. They included (1) the worker's metabolic rate, (2) physiological responses, (3) heat stress factors in the workplace environment, and (4) heat stress–related symptoms and signs experienced by the worker. The measurements of 1), 2), and 3) among the construction workers started at any time from 10 am to 3 pm, whereas in the foundry, they started when the workers started working (from 8 am to 5 pm). Personal heat stress monitors (Ques Temp II) were used to monitor auditory canal temperature (T_{ac}), an acceptable indicator for core body temperature [15,16]. Before starting to record, the sublingual temperature was measured using a digital thermometer to calibrate the Ques Temp II. Polar A300 and Polar H7 were used to monitor workers' heart rate (HR) by fastening them around the workers' wrist and chest, respectively. The participants were observed at all times to collect the data for metabolic rate calculation, i.e., activities and durations of each working task, using the observation method recommended by ISO 8996 [17]. Accordingly, the equipment installed on the subjects was also monitored. Each data set was collected for 2 hours. The heat stress factors in the working environment were monitored in 35 and 42 working areas near by the participants in all construction sites and foundries, respectively. The air temperature or dry bulb temperature (T_a), globe temperature (T_g), natural wet bulb temperature (T_{nwb}), WBGT, and relative humidity (RH) were measured and recorded by a heat stress monitor, Ques Temp ^{o}34, and air velocity was measured using Testo Model 435 HVAC and IAQ meter. Because the construction workers worked outdoors without shade at all-time, the average $WBGT_{out}$ (calculated as $WBGT_{out} = 0.7\ T_{nwb} + 0.2\ T_g + 0.1\ T_a$) in 2 hours during the physiological data collection was recorded. Although some participants were assigned several tasks a day, all tasks were done in the same working environment. The 2-hour average $WBGT_{in}$ (calculated as $WBGT_{in} = 0.7\ T_{nwb} + 0.3\ T_g$) was recorded for the foundry workers. All equipment was tested and calibrated periodically according to industrial hygiene best practices. The questionnaire used for the interview was developed for the present purpose by an expert team at the Department of Occupational Health, University of Mahidol, Bangkok. The three parts of the questionnaire focused on (1) personal details, (2) occupational history and work wear, and (3) heat stress–related symptoms and signs. The interviews were conducted by trained interviewers on the day of data collection, after 2 hours of the physiological measurements.

According to the occupational heat exposure standard of Thailand, the measurements must be taken during the hottest time of day (10 am to 3 pm). In the construction setting, this instruction could be followed, the participants being interrupted for installation of the equipment just before 10 am. Thus, the T_{ac} and HR of some construction workers might not have been at normal or at rest levels when data recording was started, especially in the morning shift where working started at 8:00 am. However, in the foundries, some workers were assigned to tasks which usually comprised 1 to 3 tasks in a cycle, and installing of the equipment should not interrupt their work. When one cycle of work (2 hours) was finished, the workers could take a break of 5 to 10 minutes. Thus, the equipment could be installed after the short break or lunch break; therefore, T_{ac} and HR were close to normal at the start of recording the data.

2.3. Data analysis

The data were described using frequency distributions, arithmetic means, ranges, and standard deviations. One-way ANOVA and paired *t* tests were used to determine whether there were statistically significant differences in the means of environmental data and participants' metabolic rate levels between the two settings studied. The overall occurrence of heat-related symptoms and signs was shown in terms of prevalence (%) of workers reporting the symptoms. The 95% confidence intervals for the prevalence was calculated based on the binomial distribution, and the differences between the study groups were tested by Fisher's exact test. Heat-related symptoms (yes/no) were then regressed on WBGT by logistic analysis, adjusting for age, body mass index, workload, metabolic rate, and employment years. Sex was not included in this analysis because of small numbers of female participants. The first order interaction of WBGT and workload was examined by likelihood ratio test. The results were expressed as odds ratios (ORs) together with their 95% confidence intervals, first entering WBGT and other factors alone in the logistic model (crude ORs) and then including all factors mentioned above, to assess potential confounding by these factors (adjusted OR). The calculations were performed using SPSS Statistics, Version 18.0, and R software release 3.50 (https://CRAN.R-project.org/).

3. Results

3.1. Characteristics of the subjects

Altogether 168 participants were recruited, 90 participants from 18 construction sites and 78 participants from 3 foundry plants. The personal characteristics of the participants, classified by setting and workload levels, are summarized in Table 1. The participants in the foundry setting were younger, and 65% consisted of men performing heavy or moderately heavy work. More than one half of the foundry workers were classified as overweight, whereas most construction workers had normal weight. The construction workers had been engaged in the current work for 11.4 years and foundry workers 4.8 years on average, with some variation depending on workload (Table 1).

The construction workers wore long sleeved shirts, cotton trousers, and hats, and they covered their face or wore weaved hats and sandals or sneakers with socks. The foundry workers wore a company short- or long-sleeve T-shirt, trousers, masks, goggles, caps, and safety shoes (Figs. 1a and b).

3.2. Working environment

Table 2 shows larger variations in all variables in the construction sites than in the foundries where the ambient conditions are largely determined by the fairly constant production processes. The maximum values of WBGT, T_a, $T_{nwb,}$ and RH were higher in the foundries than construction sites, except air velocity and T_g. The mean values of the latter variables showed little differences between the two settings. Only air velocities differed in statistical terms; however, the absolute difference was marginal. In both settings at all workload levels, noncompliance existed, i.e., WBGT in the working area could exceed the standard for the pertinent workload level.

3.3. Metabolic rates

Each participant was observed while working to estimate the metabolic rate and assigned to one of three workload groups (light, moderate, or heavy). Table 3 compares the estimated metabolic rates and WBGT by workload groups and the two study settings.

Table 1
Participants' characteristics according to industrial setting and physical workload.

Characteristics	Construction (N = 90)			Foundry (N = 78)		
	Workload			Workload		
	Light n = 23	Moderate n = 35	Heavy n = 32	Light n = 27	Moderate n = 37	Heavy n = 14
Sex (n, %)						
-Male	9 (39.1)	30 (85.7)	31 (96.9)	24 (89)	37 (100)	14 (100)
-Female	14 (60.9)	5 (14.3)	1 (3.1)	3 (11)	—	—
Age (y)						
-Mean (SD)	42.6 (11.7)	46.9 (12.9)	39.9 (13.1)	32.4 (4.7)	28.2 (5.0)	32.7 (4.8)
-Range	20–59	20–60	20–60	26–46	20–39	26–41
*Body mass index (n, %)						
-Normal	11 (47.8)	17 (48.6)	20 (62.5)	10 (37)	10 (27)	3 (21)
-Over	7 (30.5)	16 (45.7)	10 (31.3)	16 (59)	26 (70)	11 (79)
-Under	5 (21.7)	2 (5.7)	2 (6.2)	1 (4)	1 (3)	—
Employment in current work (years)						
-Mean (SD)	10.3 (7.3)	14.6 (9.5)	8.6 (8.9)	5.9 (4.4)	4.3 (2.8)	4.2 (1.8)

*Underweight: ≤18.4 kg/m^2; normal weight: 18.5 to 22.9 kg/m^2; overweight: ≥23 kg/m^2 [18].

a Construction workers

Cleaning up working area

Bricklaying

Removal of shutter boards

b Foundry workers

Slag removal

Spectrographic analysis

Repair ladle

Fig. 1. Construction and foundry workers and working environment.

The mean metabolic rate was significantly higher in construction work than in the foundries but only at light workload level, whereas at moderate workloads, the difference remained very small, despite of p-value of 0.02. The mean WBGT was significantly higher in the foundry group but only at light workload level.

3.4. Physiological responses during the monitoring period

Table 4 shows the statistics for T_{ac}, HR, the difference between the maximum HR and the HR value at minute 0 (ΔH), the respective values for T_{ac}, i.e., ΔT_{ac}, and the peak heart rate (the maximum heart rate while working) during the 2 hours monitoring period. The highest maximum T_{ac} and ΔT_{ac} of about 40 and 4.2°C, respectively, were found in the heavy workload group of the construction workers and in the moderate workload group of the foundry workers. The average T_{ac} exceeded the ACGIH standard of 38.5°C for acclimatized workers [19] in 52 of all 168 workers (31%) and in 40 construction workers (44% of 90) and 12 foundry workers (15% of 78). Out of all 52 workers who exceeded the standard, 31 (60% of 52) had T_{ac} higher than 39°C continuously for longer than 30 minutes, with respective figures of 20 (50% of 40) in construction workers and 11 (92% of 12) in foundry workers. In the construction

Table 2
Workplace environmental data in construction sites and foundry plants.

Setting	WBGT (°C)	Ta (°C)	Tg (°C)	Tnwb (°C)	RH (%)	Av (m/s)
Construction (35 working areas)						
Maximum	34.2	40.2	53.3	28.7	64.9	2.8
Minimum	24.4	27.0	33.1	21.5	18.1	0.5
Mean	31.8	35.9	47.3	26.8	35.8	1.1
SD	1.96	3.33	4.72	1.69	10.37	0.57
Foundry (42 working areas)						
Maximum	36.9	46.2	50.4	32.4	70.2	1.9
Minimum	28.7	31.4	32.6	25.7	19.5	0.5
Mean	32.4	38.5	40.0	29.12	46.3	1.4
SD	1.92	3.32	3.77	1.31	9.36	0.31
p ~*	0.543	0.906	0.131	0.319	0.354	0.003

Av, air velocity; RH, relative humidity; Ta, dry bulb temperature; Tg, globe temperature; Tnwb, natural wet bulb temperature; WBGT, wet bulb globe temperature.
* *p*-value for difference of means, from one-way ANOVA.

Table 3
Estimated metabolic rate and WBGT at three workload levels in construction sites and foundries.

Workload level	Metabolic rate (Kcal/h): Range, mean (SD)					WBGT (°C) range, mean (SD) [%WBGT exceedance]		
	N	Construction	N	Foundry	p ~*	Construction	Foundry	p ~*
Light (Construction: rebar, steel cutting, steel welding, plaster mortar; Foundry : spectrographic analysis, tapping, and core making)	23	157–198, 181.1 (9.8)	27	96–196, 150.2 (31.5)	0.000	24.4–33.6 31.3 (2.1) [0]	31.6–35.9 33.3 (1.3) [25.9]	0.000
Moderate (Construction: hammer, mixed mortar, manual lifting, and transferring stone, sand, and mortar; Foundry: casting knockout, shot blasting, and grinding)	35	204–340, 265.2 (43.2)	37	203–326, 266.9 (34.3)	0.024	24.4–34.2 31.7 (1.9) [45.7]	28.7–36.9 31.6 (2.4) [37.8]	0.922
Heavy (Construction: sawing wood, digging, manual lifting, and transferring iron, wood; Foundry: removing slag from furnace and maintaining furnace/ladle)	32	360–423, 384.7 (16.1)	14	353–420, 379.4 (22.7)	0.212	29.5–34.2 32.5 (1.1) [93.8]	29.1–34.4 31.8 (2.0) [64.3]	0.111

WBGT, wet bulb globe temperature.
* *p*-value for difference of means, from one-way ANOVA.

sites, the percentage of workers having T_{ac} higher than 38.5 increased with increasing workload while no such trend was seen in foundries. Most of the workers having $T_{ac} > 39°C$ for at least 30 minutes who did heavy or moderately heavy work (14 construction and 9 foundry workers) were in workplaces not complying to the Thai heat exposure standard.

According to the task observation records, the construction workers at all workload levels performed their tasks continuously, whereas the foundry workers at all workload levels had short breaks (10 minutes) every 2 hours in rest areas equipped with fans in light and moderately heavy workload groups and air condition in the heavy workload group. Furthermore, the work cycles in the heavy workload group in the foundries were arranged so that heavy work such as slag removal and ladle repair (workload 420–540 Kcal/h) were conducted for 30 to 50 minutes in a hot environment (T_a between 37 and 41^{o}C) and was followed by physically less demanding tasks (5–10 Kcal/h) such as preparation and transfer of raw materials using crane for the rest of 2-hour work period.

Table 4 further shows that during the monitoring period, the mean HR and ΔH increased consistently by increasing workload in construction work, whereas in the foundries, the heavy workload group stood out with an especially prominent rise of ΔH. None of the participants exhibited peak heart rate exceeding their maximum heart rate, calculated as 180 bpm minus age in years.

Heat stress-related symptoms and signs while working in a hot environment are shown in Table 5. All participants in both settings felt hot and sweaty. 30% of the workers experienced at least one symptom related to heat stress, more workers perceiving symptoms in the foundry than construction setting (39% and 22%, respectively). Out of individual symptoms, fatigue, fast pulse, and dizziness and headache were significantly more common in the foundry than construction workers. Other symptoms were more common in construction workers, but the differences versus foundry workers did not reach statistical significance.

Table 6 compares the prevalence of symptoms between workers with T_{ac} higher and lower than the recommended standard of 38.5°C and also compares workplaces compliant and noncompliant with the Thai Labor standard. While 50 workers out of all 168 (30%) had at least one heat stress–related symptom, 35% of those with $T_{ac} > 38.5°C$ had symptoms, compared with 27% of those having $T_{ac} \leq 38.5°C$.

Table 6 further shows that 92 workers (55%) worked in compliant workplaces. Among them, 21% had T_{ac} higher than 38.5°C, compared with 44% in noncompliant workplaces. In light work, 26% of participants had symptoms in compliant workplaces but 100% in noncompliant workplaces, with respective percentages of 14% and 37% in moderately heavy work, and 0% and 38%, respectively, in heavy work. The trend was similar separately for workers having T_{ac} lower than 38.5°C, those working in noncompliant workplaces having consistently higher prevalence of heat stress-related symptoms.

Table 7 shows the results from logistic regression of heat stress–related symptoms on WBGT, work-related, and personal factors. In the univariate models, only WBGT proved a significant factor, with OR of 1.85 (95% CI 1.44–2.48). In models adjusting for age, BMI, workload, metabolic rate, and work experience, the effect of WBGT remained unchanged. Also the independent effects of all adjustors remained unaffected, possibly excepting heavy workload and long work experience, which were associated with a slightly increased OR. However, none of the variables other than WBGT reached statistical significance in unadjusted or adjusted models.

Table 1 in Supplement A tests whether the association of heat-related symptoms is different at different workloads. The ORs for WBGT exceed unity in all instances, and they are higher in the heavy workload group than in other groups. However, the interaction between WBGT and workload remains insignificant at 0.05 level, indicating no significant departure from the null hypothesis that the effect of WBGT would differ by workload.

4. Discussion

4.1. *Summary of findings*

Approximately, one half of the participants worked in a compliant environment, where 79% of workers had an average T_{ac} below 38.5°C, whereas in noncompliant workplaces, only 58% had T_{ac} below 38.5°C. More of the workers having $T_{ac} > 38.5°C$ had at least some heat stress–related symptoms compared with those having lower T_{ac} (35% and 27%, respectively), and the symptoms were consistently more common in noncompliant than compliant workplaces (43% and 18%, respectively). Furthermore, in 60% of the workers (mainly in noncompliant workplaces) who had T_{ac} higher than the standard of 38.5°C, their T_{ac} remained higher than 39°C continuously for longer than 30 minutes. Thus, in workplaces complying with the Ministry of Labor heat exposure standard, the vast majority of workers were protected but only one half in workplaces not complying with the standard. The most significant factor underlying the heat stress–related symptoms was workplace temperature, which increased the odds for having heat-related symptoms by a factor of 1.83 per one degree increase in WBGT, independently of personal and other work-related factors.

Table 4
Physiological responses during the measurement period.

Workload		Construction (N = 90)						Foundry (N = 78)					
		T_{ac} (°C)	n (%)T_{ac} >38.5 °C	ΔT_{ac} (°C)	HR (bpm)	ΔH (bpm)	PHR (bpm)	T_{ac} (°C)	n (%)T_{ac} >38.5 °C	ΔT_{ac} (°C)	HR (bpm)	ΔH (bpm)	PHR (bpm)
Light	Max.	39.41	4 (17)	3.40	97	75.00	160	39.8	3 (11)	3.30	139	66.00	116
	Min.	36.60		0.10	70	6.00	121	36.8		0.20	85	12.00	85
	Mean	37.88		1.53	82.8	28.13	137.4	37.7		1.48	102	29.77	95
	SD	0.94		0.85	6.77	13.30	11.7	0.72		0.83	12.69	13.60	7.93
Moderate	Max.	39.58	14 (40)	4.00	126	65.00	152	40.1	9 (24)	4.20	143	46.38	132
	Min.	36.62		0.40	80	18.00	95	36.8		0.10	79	2.55	71
	Mean	38.09		1.83	96.6	34.83	116	38.0		1.36	102	28.39	95
	SD.	0.82		0.86	11.03	12.06	12.26	0.92		1.04	16.33	8.83	13.27
Heavy	Max.	40.08	22 (69)	4.20	127	68.00	150	38.4	0 (0)	3.30	123	75.68	113
	Min.	37.04		0.10	82	19.00	95	37.0		0.50	79	24.37	74
	Mean	38.61		2.29	105.8	36.94	126.7	37.9		1.81	106	52.96	97
	SD.	0.83		0.87	9.46	11.72	10.33	0.47		0.94	12.19	14.35	11.75
All	Max.	40.1	40 (44)	4.2	127	75	160	40.1	12 (15)	4.2	143	76	159
	Min.	36.6		0.1	70	6	120	36.8		0.1	79	3	97
	Mean	38.2		1.9	96.4	34	137	37.8		1.5	103	33	123
	SD	0.9		0.9	12.9	12.6	12.9	0.8		0.9	14.4	14.7	17.5

HR, heart rate; PHR, peak heart rate; T_{ac} auditory canal temperature.

4.2. Validity of measurements

Because ambient temperature and air velocity could affect the T_{ac}, the participants were observed at all times to make sure that the earplug covering their ear canal sensor was in place throughout the measurement period. Moreover, air temperature and air velocity in the working areas were in such a range that T_{ac} should not be affected (Table 2) [20,21]. We therefore believe that the measured T_{ac} represents well the actual core temperature. Validity of answers to heat symptom questions can only be assessed in terms of face validity, because they are based on subjective feelings which cannot be compared with any external gold standard. Because the questions were obviously understandable to an average participant, we believe that their face validity is reasonable.

The T_{ac} reflected the work pattern quite well. Thus in all groups, excepting the heavy workload group in the foundry, T_{ac} varied between 37 and 40°C over the 2-hour monitoring period, whereas in the heavy workload group in the foundries, especially in slag removal, T_{ac} went up and remained above 39°C during the first 30 to 50 minutes before decreasing to approximately 38 to 38.5°C for the rest of the monitoring period. The "healthy worker effect" could be a factor influencing T_{ac} among the foundry workers, especially those in the heavy workload group where the workforce has been carefully selected.

4.3. Interpretation of the results

The current law protects most of the workers because 79% of those who worked in compliant workplaces had $T_{ac} \leq 38.5$°C, and a similar proportion of them had no heat stress–related symptoms or signs. However, many participants (45%) did not work in compliant workplaces and had significantly more often a high T_{ac} and more heat-related symptoms. The underlying reasons include that the current law is impractical and ambiguous. The law defines the upper limits for WBGT according to workload levels and specifies the period of monitoring to assess heat exposure. However, it leaves the work/rest regimen undefined, assuming that the worker takes short breaks when appropriate. In the foundries, the workers to take a 10 minute break every 2 hours, whereas the construction workers work continuously until lunch break in the morning and until end of the working day in the afternoon.

Although most construction work is self-regulated, its intensity is affected by time pressures, financial incentives, and peer pressures [22]. Time pressures obviously exists in construction business in Thailand, as shown by its high turnover rate; thus, lack of labor force is normally observed [23]. Furthermore, natural phenomena such as rains and storms could affect outdoor work causing delays and rushes to keep on schedule. For foundry workers, performing heavy work in a hot environment means extra pay; and thus, peer pressures and financial incentives could affect their speed of work.

Table 5
Prevalence (P) of heat-related symptoms[§] separately for construction and foundry workers.

Symptoms/signs[†]	Construction (N = 90)			Foundry (N = 78)			p ~[‡]	All (N = 168)		
	n	P	95% CI	n	P	95% CI		n	P	95% CI
Any symptoms	20	22	(14–32)	30	39	(28–50)	0.028	50	30	(23–37)
Fatigue	6	7	(3–14)	24	31	(21–42)	0.000	30	18	(12–25)
Fast pulse	2	2	(0–8)	23	30	(20–41)	0.000	25	15	(10–21)
Cramps	13	14	(8–23)	6	8	(3–16)	0.223	19	11	(7–17)
Dizziness/headache	2	2	(0–8)	11	14	(7–24)	0.007	13	8	(4–13)
Giddiness	4	4	(1–11)	1	1	(0–7)	0.374	5	3	(1–7)
Clammy skin	4	4	(1–11)	0	0	(0–5)	0.124	4	2	(1–6)
Restlessness	3	3	(1–9)	0	0	(0–5)	0.249	3	2	(0–5)

n = number of subjects having symptoms, N = number of respondents. 95% confidence interval[*] for prevalence are given in parentheses.

[*] From binomial distribution.

[†] Based on question: "Do you have the following symptoms during work?"

[‡] From Fisher exact test.

[§] Cramps, fast pulse, dizziness/headache, giddiness, clammy skin, fatigue, restlessness, rash, and red, hot, and dry skin.

Table 6
Numbers (percentages) of participants with signs or symptoms of heat exposure[*], classified according to core body temperature and compliance with the Thai Labor standard for heat exposure.

Workload	T_{ac} (°C)	Symptoms n/N (%)		
		Compliant workplaces	Noncompliant workplaces	All workplaces
Light	>38.5	2/9 (22)	1/1 (100)	3/10 (30)
	≤38.5	9/34 (26)	6/6 (100)	15/40 (38)
	Total	11/43 (26)	7/7 (100)	18/50 (36)
Moderate	>38.5	2/9 (22)	6/12 (50)	8/21 (38)
	≤38.5	4/33 (12)	5/18 (28)	9/51 (18)
	Total	6/42 (14)	11/30 (37)	17/72 (24)
Heavy	>38.5	0/1 (0)	7/19 (37)	7/20 (35)
	≤38.5	0/6 (0)	8/20 (40)	8/26 (31)
	Total	0/7 (0)	15/39 (38)	15/46 (33)
All workload classes	>38.5	4/19 (21)	14/32 (44)	18/51 (35)
	≤38.5	13/73 (18)	19/44 (43)	32/117 (27)
	Total	17/92 (18)	33/76 (43)	50/168 (30)

n = no. of participants reporting any symptom(s) listed in Table 6, N = no. of participants answering the question.

[*] Cramps, fast pulse, dizziness/headache, giddiness, clammy skin, fatigue, restlessness, rash, and red, hot, and dry skin.

Obviously, short breaks in the foundries and self-regulation in the construction sites were not enough to cool down the worker's temperature.

Because Thailand is located in a tropical zone, WBGT is usually high and can exceed the law-defined standard even at light workload levels. As shown in Table 2, the average and maximum WBGT at the construction sites were 31.8°C and 34.2°C, respectively, and 34.2°C and 36.9°C, respectively, in the foundries, whereas the standard WBGTs for light, moderate, and heavy workloads are 34°C, 32°C, and 30°C, respectively. Therefore, reducing WBGT to the levels required by the standard while maintaining continuous working would be difficult and expensive. An alternative method would be to set up work/rest cycles as recommended by or used in some organizations or countries [4,6,24].

The objective of this study was not to compare the construction and foundry settings, but some differences can be observed between them that affected the heat strain and may necessitate law amendments, e.g., work/rest cycles mentioned above, heat stress monitoring, heat exposure control and management, and heat hazard recognition. The major factor accounting for these differences is the current law. First, the Department of Labor Protection and Welfare [25] defines "foundry" as a type of establishment where heat stress monitoring is needed, whereas no such definition exists for construction and other outdoor work. While a hot workplace is defined as an establishment with a heat source or work which may cause hazard to workers because of heat, it is not recognized that the sun is an occupational heat source in outdoor work such as construction and agriculture, and the workers could face high risk from heat exposure [19,24]. Second, safety officers, whose responsibilities also cover industrial hygiene work, are required by law to work in foundries but not in small and medium size establishments such as the construction sites in this study. Therefore, WBGT is not monitored nor heat stress controlled in construction industry. As a result, the construction workers do not have certain occupational health services which the foundry workers have, such as rest areas in shade, cool drinking water and periodic medical examinations [26]. Therefore, this study strongly suggests that the work/rest schedules for all workload levels and definitions for the types establishment involving heat exposure should be defined by the law.

Table 7
Odds ratios (95% confidence intervals) from logistic regression of heat stress–related symptoms[*] on personal, environmental, and work-related factors.

Explanatory variable	Coding	Single variable models	Full model
WBGT	°C	1.85 (1.44–2.48)	1.82 (1.41–2.46)
Age	20–40 y	1	1
	21–60 y	0.70 (0.34–1.40)	0.71 (0.30–1.64)
BMI	Underweight	0.73 (0.15–2.80)	0.51 (0.09–2.33)
	Normal.	1	1
	Overweight	0.72 (0.36–1.42)	0.76 (0.35–1.67)
Workload	Light	1	1
	Moderate	0.55 (0.11–1.60)	0.90 (0.20–3.95)
	Heavy	0.86 (0.59–5.76)	1.33 (0.08–23.16)
Metabolic rate	Kcal/h	0.998 (0.995–1.002)	0.999 (0.987–1.011)
Work experience	0–1 y	1	1
	1–30 y	1.32 (0.51–3.84)	1.61 (0.52–5.50)

BMI, body mass index; WBGT, wet bulb globe temperature.

[*] Cramps, fast pulse, dizziness/headache, giddiness, clammy skin, fatigue, restlessness, rash, and red, hot, and dry skin.

Supplement B shows the ACGIH formula [19] to calculate appropriate work-rest cycles, with an example based on the present data. The smaller the $WBGT_r$, the shorter the rest period; thus, providing a cool rest area would shorten the recovery time. Under conditions complying with the standard, the length of the rest period ranges from 13 to 44 minutes for 1 hour work cycles, depending on workload, and from 25 to 88 minutes for 2 hour work cycles. In case temperature in the rest area would be 25°C (air conditioner room), the rest time for a 1 hour cycle of heavy work would be reduced to approximately 25 minutes. Furthermore, to have shorter recover times, the work cycle should be kept to 1 hour instead of 2 hours.

Conflicts of interest

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.shaw.2020.09.008.

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