

Online Supplementary Material
Annals of Work Exposures and Health

**Assessment of Heat Stress Exposure among Construction Workers in
the Hot Desert Climate of Saudi Arabia**

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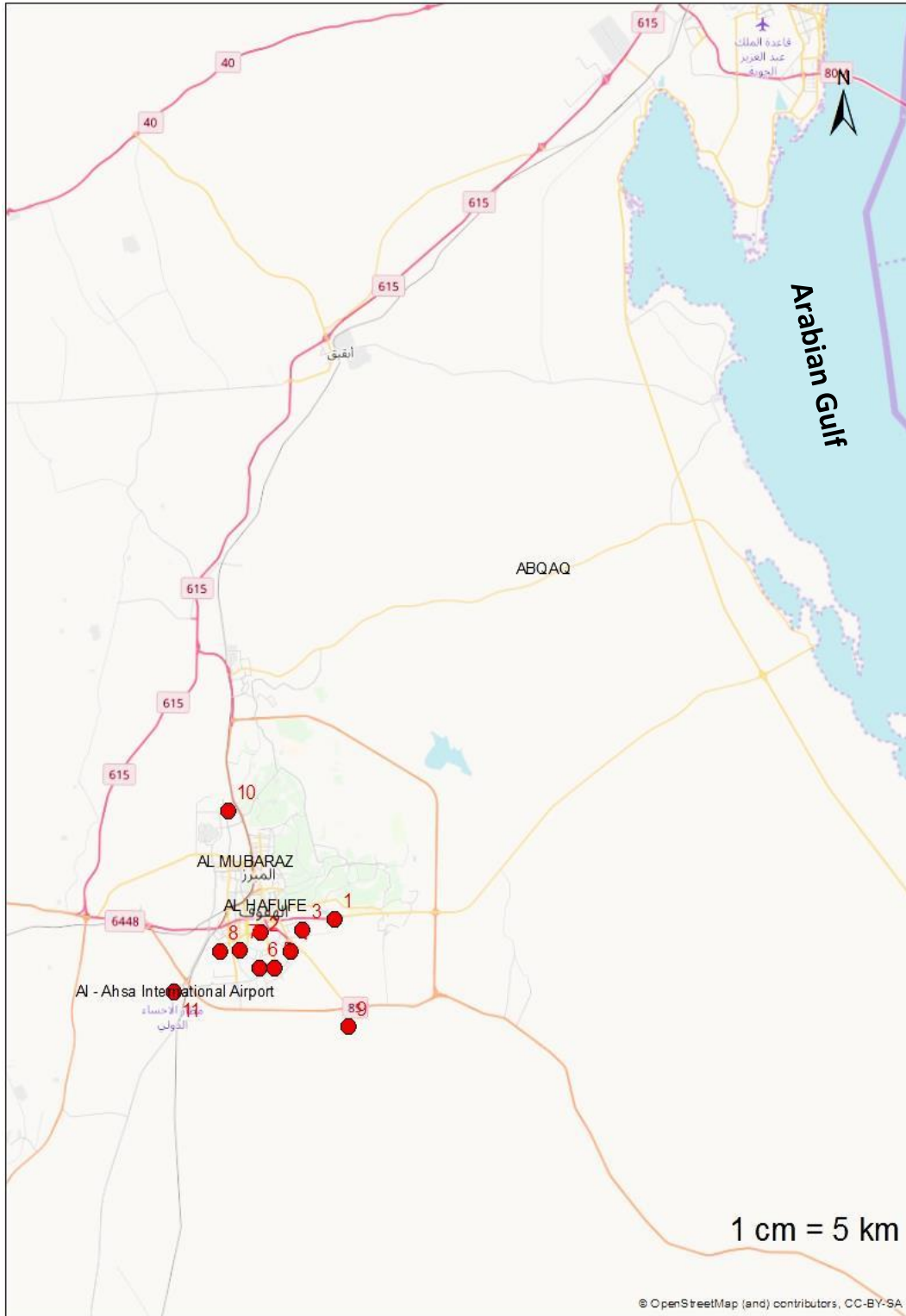


Figure S-1. Locations of the ten construction sites in Al-Ahsa province, Saudi Arabia, June – September 2016.

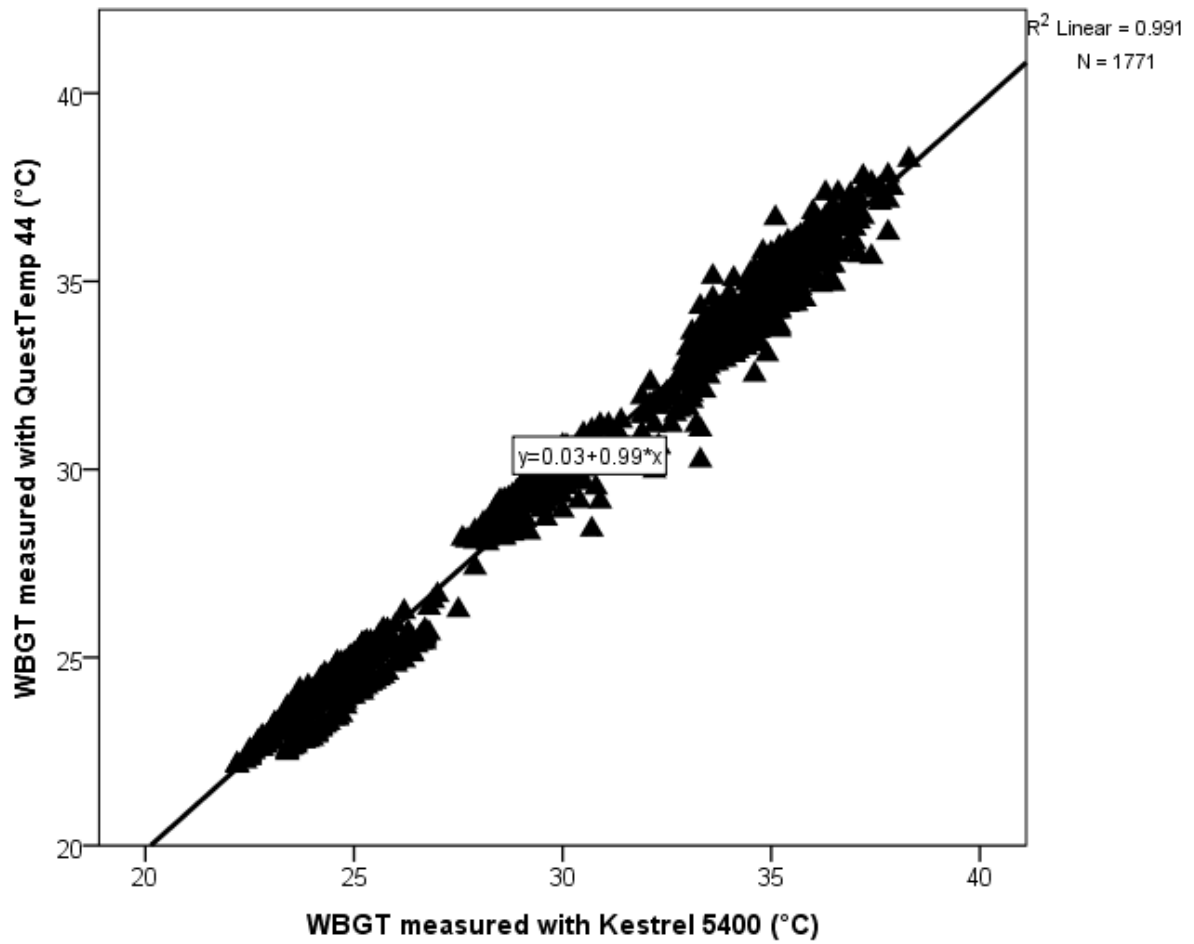


Figure S-2. Comparison of the WBGT measured by two portable devices used for environmental heat exposure monitoring in Al-Ahsa Province, Saudi Arabia, June – September 2016.

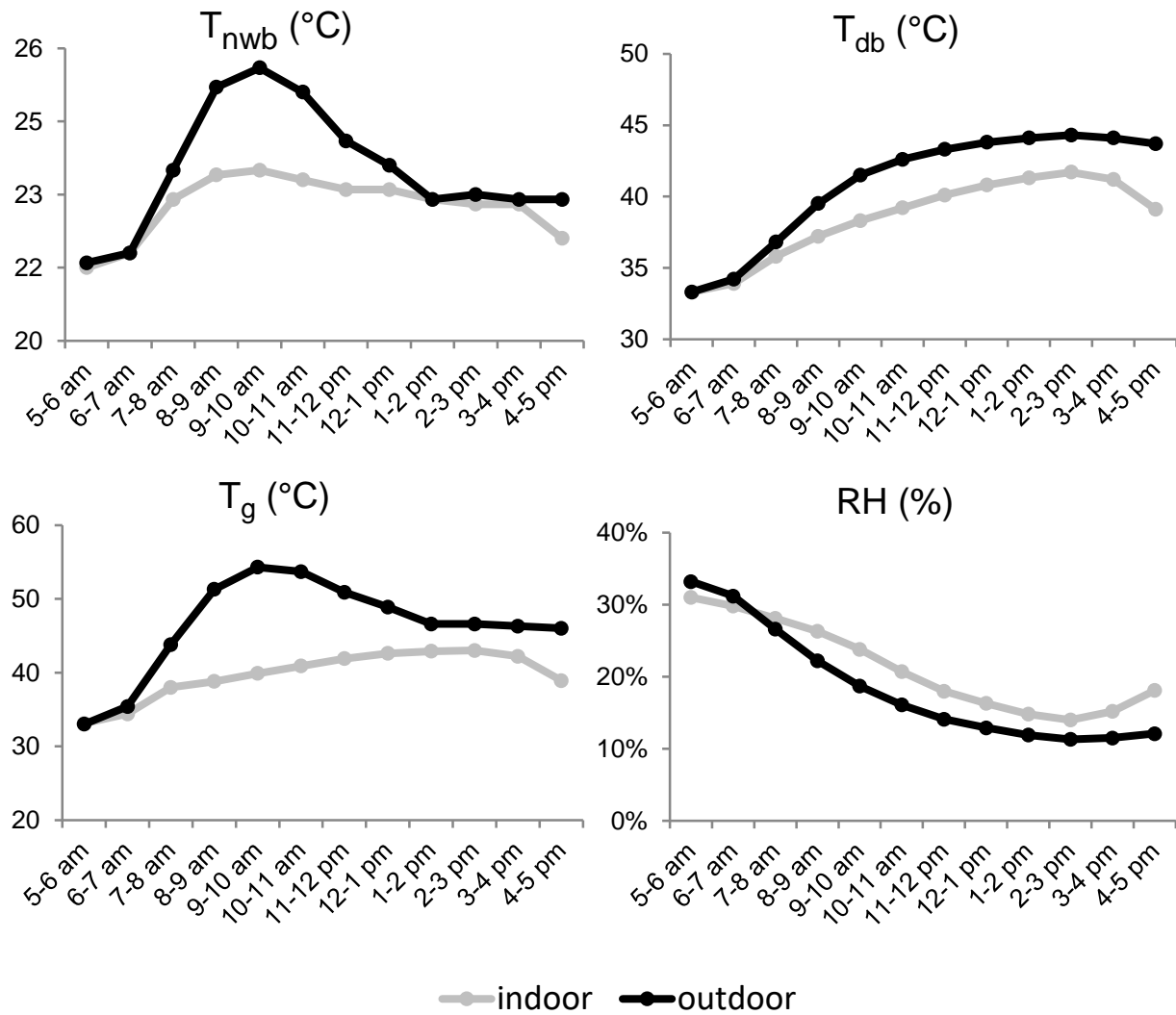





Figure S-3. Indoor and outdoor hourly mean natural wet bulb temperature (T_{nwb}), globe temperature (T_g), dry bulb temperature (T_{db}), and relative humidity (RH), for ten residential construction sites in Al-Ahsa Province, Saudi Arabia, June – September 2016.

Table S-1. Indoor and outdoor environmental parameters (mean \pm SD) measured at ten construction sites in Al-Ahsa Province, Saudi Arabia, June – September 2016.

Site	No. of days	Indoor					Outdoor				
		T _{db} (°C)	T _g (°C)	T _{nwb} (°C)	RH (%)	WBGT (°C)	T _{db} (°C)	T _g (°C)	T _{nwb} (°C)	RH (%)	WBGT (°C)
1 ^a	9	38.1 \pm 3.6	39.0 \pm 4.7	23.5 \pm 3.2	25.3 \pm 14.1	28.1 \pm 2.9	40.3 \pm 4.4	46.2 \pm 7.5	24.8 \pm 3.6	24.2 \pm 17.9	30.6 \pm 3.5
2 ^a	9	39.0 \pm 3.9	41.5 \pm 7.9	22.6 \pm 2.3	19.7 \pm 11.7	28.3 \pm 3.3	41.1 \pm 4.4	45.7 \pm 6.5	22.9 \pm 2.5	16.7 \pm 13.0	29.3 \pm 2.8
3	9	38.5 \pm 3.8	40.1 \pm 6.8	23.2 \pm 2.0	22.6 \pm 10.8	28.2 \pm 2.8	40.7 \pm 4.8	47.4 \pm 8.8	24.1 \pm 2.5	20.0 \pm 12.0	30.3 \pm 3.5
4	9	38.8 \pm 3.5	39.1 \pm 3.6	22.0 \pm 1.7	17.8 \pm 8.5	27.0 \pm 1.9	41.8 \pm 4.5	46.8 \pm 7.4	22.9 \pm 1.8	14.3 \pm 9.3	29.5 \pm 2.8
5	9	37.2 \pm 4.4	38.0 \pm 6.7	21.8 \pm 2.6	21.4 \pm 10.3	26.7 \pm 3.3	40.4 \pm 4.6	45.7 \pm 7.8	22.6 \pm 2.8	16.7 \pm 11.0	28.8 \pm 3.3
6	9	38.1 \pm 4.5	40.3 \pm 7.8	21.9 \pm 2.1	18.5 \pm 7.4	27.2 \pm 3.4	40.4 \pm 4.6	44.7 \pm 7.0	22.0 \pm 2.1	15.4 \pm 7.7	28.4 \pm 2.8
7	9	39.0 \pm 4.7	40.7 \pm 7.8	22.2 \pm 2.0	18.3 \pm 10.9	27.7 \pm 3.4	40.0 \pm 4.9	45.0 \pm 7.8	22.6 \pm 2.2	17.2 \pm 12.0	28.8 \pm 3.1
8 ^a	6	38.8 \pm 3.7	39.1 \pm 3.9	23.0 \pm 1.9	21.4 \pm 8.6	27.8 \pm 2.2	41.8 \pm 4.7	48.2 \pm 8.7	24.1 \pm 2.7	17.2 \pm 8.4	30.8 \pm 3.7
9	6	39.3 \pm 2.8	39.4 \pm 2.7	24.2 \pm 2.0	24.5 \pm 12.7	28.7 \pm 1.6	42.7 \pm 4.5	48.9 \pm 8.3	25.4 \pm 2.5	20.8 \pm 16.1	31.8 \pm 3.1
10 ^a	6	38.8 \pm 2.3	39.0 \pm 2.2	24.2 \pm 3.3	26.1 \pm 15.4	28.6 \pm 2.4	41.6 \pm 4.3	47.6 \pm 7.5	25.5 \pm 3.7	24.3 \pm 19.4	31.6 \pm 3.4

^a These sites are not compliant with the mandatory afternoon outdoor work ban (12–3 p.m.).

Table S-2. Description of the residential construction work activities performed by workers in Al-Ahsa Province, Saudi Arabia, June – September 2016.

Work activity	Description
<p>A) Site preparation</p> 	<p>Site preparation occurs in the early stages of the construction process. The work involves a variety of physically demanding activities carried out by general laborers, with machine operators when needed. These include transporting material, the demolition and removal of aboveground unwanted items, excavation, backfilling and leveling to clear and lay out the site. Site layout is performed by experienced, qualified carpenters under the guidance of the onsite engineer. As observed, these activities are carried out 100% outdoors under direct exposure to sunlight.</p>
<p>B) Formwork</p> 	<p>For concrete foundations, columns, beams, slabs and other structures, formwork is assembled to mold concrete to prescribed sizes and designs. The formwork is removed one to three weeks after the concrete inside has hardened. This step is performed by skilled carpenters with help from general laborers under the guidance of onsite foremen. The work involves frequent hammering, sawing, carrying, and moving activities that are performed nearly 100% of the time under direct sun.</p>
<p>C) Steel Reinforcement</p> 	<p>Steel reinforcement involves cutting, connecting, and assembling steel bars and other steel materials, according to reinforcement designs. The reinforcements are either assembled outside the formwork and then moved and installed in the intended location, as in the case of foundations and columns, or they are assembled directly in the formwork, as in the case of beams and slabs. This work requires the use of hand tools for twisting, cutting, carrying, and lifting steel reinforcement pieces to elevated heights. All of these activities are performed by skilled ironworkers under direct exposure to sunlight nearly 100% of the time.</p>

Work activity	Description
<p data-bbox="126 218 581 247">D) Pouring and Finishing of Concrete</p> 	<p data-bbox="784 218 1549 682">The premixed concrete is delivered to the worksite on a predetermined schedule. The concrete is then quickly transferred from the mixing truck to the placement location via a concrete pump. The presence of extra workers for pouring and finishing the concrete mix was observed at the work site because the pump worked continuously and supplied the concrete rapidly. Workers are required to work at a fast pace, pushing the concrete through the formwork and reinforcements using shovels and concrete vibrators, then spreading and leveling the concrete surface with a screening board or, for large slabs, a screening “helicopter” machine. Workers of all categories were observed to participate in these activities. As the premixed concrete is delivered during the day, the work is performed 100% outdoors under exposure to direct sunlight.</p>
<p data-bbox="126 714 354 743">E) Masonry Work</p> 	<p data-bbox="784 714 1549 1045">Masonry work consists of laying bricks or stones on cement mixture/mortar (water, sand and cement mix) vertically and horizontally to erect interior and exterior walls. Masonry also includes forming lintels around windows and doors. This work is performed mainly by skilled masons with assistance from laborers who are generally responsible for preparing and delivering the cement mixture/mortar and building materials (block, bricks, or stones). Approximately 90% of this work was performed outdoors with direct sun exposure in a standing position on the ground or on scaffolding.</p>
<p data-bbox="126 1138 548 1167">F) Roof, Floor and Wall Insulation</p> 	<p data-bbox="784 1138 1549 1774">Insulation installation involves the use of waterproofing and thermal insulation materials. The work starts with waterproofing in the early stages of construction. Using brushes or rollers, foundations and underground retaining walls are coated with a bituminous liquid membrane. The second part of the insulation process starts concurrently with the erection of exterior walls that are a single layer of thermal blocks or double walls that use ordinary blocks with the cavity filled with the thermal insulation material (cavity wall insulation). Later, the roof of the building is insulated with polystyrene thermal insulation materials (boards or granules mixed with cement). Then, sheets of bituminous waterproofing membrane are laid over the thermal insulation, and the joints between sheets are sealed with heat from propane torches. Bathroom and kitchen concrete floors are also insulated with a waterproof bituminous liquid membrane using brushes or rollers. With the exception of the wall insulation, all insulation work is carried out by workers employed by subcontractors. Approximately 80% of the insulation work activities are executed outdoors under direct sun, mostly in a squatting position.</p>




Work activity	Description
<p data-bbox="126 226 380 254">G) Utility Installation</p> 	<p data-bbox="784 226 1544 527">Plumbing and electrical installation are carried out by subcontracted technicians and workers. In the early stages of construction, these activities are limited to the installation of electrical lines and of plumbing pipes and fittings in walls and ceilings. After the completion of building structures, the finishing stages of plumbing and electricity are conducted. This type of work requires pulling and hammering in sitting and standing positions on the ground or on ladders and is performed approximately 50% indoors and 50% outdoors.</p>
<p data-bbox="126 646 293 674">H) Plastering</p> 	<p data-bbox="784 646 1544 1476">Plastering and tiling are usually two distinct jobs with similar activities; the workers tend to be either plasterers or tilers. The plastering and tiling steps are generally carried out in three stages. Plastering starts by filling all cavities and cracks on the surfaces of the walls with a cement mixture. Then, a layer of spatterdash (a wet mixture of cement) is applied on the surface areas of the walls and ceilings to form a rough texture. After that, a layer or two of plaster is applied to the wall or ceiling. When the plaster mixture starts to harden and hold together, the surface is evened out by a long straight aluminum edge and then smoothed by a wooden float and wet sponge to create the desired texture finish. Similarly, tiling is conducted in three stages. The first stage is the rough plastering of the walls and leveling off the floor with a concrete mixture or with sand and gravel. The next day, wall or floor tiles are laid after applying a layer of cement or tile adhesive mortar. In the final stage, a grout mixture is applied to fill in the joints between the tiles using a rubber grout float or a squeegee. Depending on the location of the plastering and tiling, the work can be outdoors or indoors in a small confined space. Approximately 60% of the plastering work and approximately 20% of the tiling are conducted outdoors. These types of work are performed by skilled craftsmen in various postures on the ground or on scaffolding. They require the use of cutting and grinding tools/machines. Generally, plastering work is highly demanding, with continuous hand and body movements.</p>
<p data-bbox="126 1077 245 1104">I) Tiling</p> 	

Table S-3. WBGT-based exposure limits (°C).

Work/Rest cycle	Workload category		
	Light	Moderate	Heavy
100% work	30.8	28.2	26.6
75% work + 25% rest	31.2	29.0	27.6
50% work + 50% rest	31.8	30.1	28.8
25% work + 75% rest	32.3	31.3	30.5
Caution ^a	33.0	33.0	33.0

^a Caution => TLV at rest (115 Watts, for metabolic rate at rest), which is considered the point at which work needs to be stopped.
Source: American Conference of Governmental Industrial Hygienists (ACGIH). (2009) *Heat Stress and Strain: TLV® Physical Agents*. Cincinnati, Ohio: ACGIH.

Table S-4. Heat Index (HI)-based exposure limits ^a.

HI (° C) ^b	Light	Moderate	Heavy
35.0	<EL	<EL	<EL
35.5	<EL	<EL	45/15
36.0	<EL	<EL	45/15
36.5	<EL	<EL	45/15
37.0	<EL	<EL	40/20
37.5	<EL	<EL	40/20
38.0	<EL	<EL	35/25
38.5	<EL	45/15	35/25
39.0	<EL	45/15	30/30
39.5	<EL	45/15	25/35
40.0	<EL	40/20	25/35
40.5	<EL	40/20	25/35
41.0	<EL	35/25	20/40
41.5	<EL	30/30	20/40
42.0	<EL	30/30	15/45
42.5	<EL	25/35	15/45
43.0	<EL	25/35	15/45
43.5	<EL	20/40	Caution
44.0	<EL	20/40	Caution
44.5	45/15	15/45	Caution
45.0	45/15	15/45	Caution
45.5	45/15	15/45	Caution
46.0	40/20	Caution	Caution
46.5	35/25	Caution	Caution
47.0	30/30	Caution	Caution
47.5	25/35	Caution	Caution
48.0	20/40	Caution	Caution
48.5	20/40	Caution	Caution
49.0	15/45	Caution	Caution
49.5	Caution	Caution	Caution

^a Work/Rest cycle is expressed as minutes of work per minutes of rest in each hour; EL = Exposure Limit; Caution = > EL at rest (115 Watts, for metabolic rate at rest), which is considered the point at which work needs to be stopped.

^b Low Radiant Heat ($T_g = T_{db} + 3.9^\circ\text{C}$): Add 2°C to measured HI; and High Radiant Heat ($T_g = T_{db} + 7.2^\circ\text{C}$): Add 3°C to measured HI, for $WBGT_{outdoor}$, and add 5°C to measured HI, for $WBGT_{indoor}$. Then identify the Work/Rest cycles accordingly.

Source: Bernard TE, Iheanacho I. (2015) Heat index and adjusted temperature as surrogates for wet bulb globe temperature to screen for occupational heat stress. *J Occup Environ Hyg*; **12**: 323-333.

Table S-5. Humidex (HD)-based exposure limits (° C).

HD 1^a	Response	HD 2^a
25 – 29	Supply water to workers on an “as needed” basis	32 – 35
30 – 33	Post ‘Heat Stress Alert’ notice Encourage workers to drink extra water Start recording hourly temperature and relative humidity	36 – 39
34 – 37	Post ‘Heat Stress Warning’ notice Notify workers that they need to drink extra water Ensure workers are trained to recognize symptoms	40 – 42
38 – 39	Work with 15 minutes of relief per hour can continue Provide adequate quantities of cool (10 – 15 ° C) water At least one cup of water every 20 minutes per worker Workers with symptoms should seek medical attention	43 – 44
40 – 42	Work with 30 minutes of relief per hour can continue, in addition to the provisions listed previously	45 – 46 ^b
43 – 44	If feasible, work with 45 minutes of relief per hour can continue, in addition to the provisions listed previously	47 – 49 ^b
> 45 ^b	Only medically supervised work can continue	> 50 ^b

^a HD 1 is for acclimatized workers performing heavy work; and HD 2 is for acclimatized workers performing moderate work.

Note: Adjustment for Radiant Heat: For outdoor work in direct sunlight between 10 am and 5 pm, add 2-3°C to HD (pro-rate according to percentage cloud cover) and for indoor heat exposures, use common sense to judge whether the exposure involves radiant heat then add 2-3°C to HD accordingly.

^b At HD exposure above 45°C, job-specific controls are required to manage heat stress.

Source: Occupational Health Clinics for Ontario Workers (OHCOW). (2014) *Humidex Based Heat Response Plan* [Online].

Available: https://www.ohcow.on.ca/edit/files/general_handouts/Humidex%20Based%20Heat%20Response%20Plan%20-%20June%2010%202014.pdf [Accessed 29 November 2018].

Table S-6. Cross-tabulation of hourly workability as determined by the HI and the WBGT index along with the level of agreement (weighted kappa scores, κ_w) in relation to the workload and work setting for a total of 973 working hours.

		HI						
WBGT	[1]	[2]	[3]	[4]	[5]	Total	κ_w	[95% CI]
Outdoors, moderate work							0.89	[0.87, 0.91]
[1] 60 minutes	258	35	8	1	0	302		
[2] 45 minutes	8	24	24	6	0	62		
[3] 30 minutes	8	12	96	34	0	150		
[4] 15 minutes	2	3	50	139	2	196		
[5] 0 minutes	1	3	11	115	133	263		
Total	277	77	189	295	135	973		
Outdoors, heavy work							0.90	[0.88, 0.92]
[1] 60 minutes	124	24	7	2	0	157		
[2] 45 minutes	6	21	52	2	0	81		
[3] 30 minutes	1	10	61	38	0	110		
[4] 15 minutes	1	0	20	202	10	233		
[5] 0 minutes	0	1	5	124	262	392		
Total	132	56	145	368	272	973		
Indoors, moderate work							0.85	[0.82, 0.88]
[1] 60 minutes	536	62	5	1	0	604		
[2] 45 minutes	11	59	24	1	0	95		
[3] 30 minutes	6	6	98	5	0	115		
[4] 15 minutes	2	2	9	42	6	61		
[5] 0 minutes	4	8	27	30	29	98		
Total	559	137	163	79	35	973		
Indoors, heavy work							0.88	[0.86, 0.90]
[1] 60 minutes	264	57	5	0	1	327		
[2] 45 minutes	12	62	87	1	0	162		
[3] 30 minutes	2	12	144	27	0	185		
[4] 15 minutes	3	3	12	142	1	161		
[5] 0 minutes	1	2	11	60	64	138		
Total	282	136	259	230	66	973		

Table S-7. Cross-tabulation of hourly workability as determined by the HD and the WBGT index along with the level of agreement (weighted kappa scores, κ_w) in relation to the workload and work setting for a total of 973 working hours.

WBGT	HD					Total	κ_w	[95% CI]
	[1]	[2]	[3]	[4]	[5]			
Outdoors, moderate work							0.80	[0.77, 0.82]
[1] 60 minutes	295	6	0	1	0	302		
[2] 45 minutes	43	12	7	0	0	62		
[3] 30 minutes	16	85	45	4	0	150		
[4] 15 minutes	7	37	103	49	0	196		
[5] 0 minutes	3	10	40	125	85	263		
Total	364	150	195	179	85	973		
Outdoors, heavy work							0.91	[0.90, 0.93]
[1] 60 minutes	113	39	3	2	0	157		
[2] 45 minutes	3	41	35	2	0	81		
[3] 30 minutes	1	9	50	45	5	110		
[4] 15 minutes	0	3	8	121	101	233		
[5] 0 minutes	0	0	1	38	353	392		
Total	117	92	97	208	459	973		
Indoors, moderate work							0.71	[0.67, 0.76]
[1] 60 minutes	597	3	3	1	0	604		
[2] 45 minutes	62	32	0	1	0	95		
[3] 30 minutes	9	76	30	0	0	115		
[4] 15 minutes	4	2	25	27	3	61		
[5] 0 minutes	21	17	18	17	25	98		
Total	693	130	76	46	28	973		
Indoors, heavy work							0.88	[0.86, 0.90]
[1] 60 minutes	247	78	1	0	1	327		
[2] 45 minutes	2	80	77	2	1	162		
[3] 30 minutes	2	2	107	71	3	185		
[4] 15 minutes	3	2	1	104	51	161		
[5] 0 minutes	1	1	11	31	94	138		
Total	255	163	197	208	150	973		