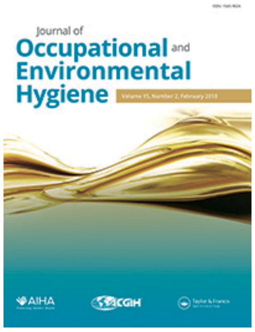

Taylor & Francis
Taylor & Francis Group

Journal of Occupational and Environmental Hygiene

ISSN: 1545-9624 (Print) 1545-9632 (Online) Journal homepage: http://www.tandfonline.com/loi/uoeh20

Assessment of occupational exposure to heat stress and solar ultraviolet radiation among groundskeepers in an eastern North Carolina university setting

Nicole Beck, Jo Anne G. Balanay & Terri Johnson

To cite this article: Nicole Beck, Jo Anne G. Balanay & Terri Johnson (2018) Assessment of occupational exposure to heat stress and solar ultraviolet radiation among groundskeepers in an eastern North Carolina university setting, Journal of Occupational and Environmental Hygiene, 15:2, 105-116, DOI: 10.1080/15459624.2017.1392530

To link to this article: https://doi.org/10.1080/15459624.2017.1392530

Accepted author version posted online: 01 Nov 2017.
Published online: 01 Nov 2017.

JOURNAL OF OCCUPATIONAL AND ENVIRONMENTAL HYGIENE
2018, VOL. 15, NO. 2, 105–116
https://doi.org/10.1080/15459624.2017.1392530

Assessment of occupational exposure to heat stress and solar ultraviolet radiation among groundskeepers in an eastern North Carolina university setting

Nicole Beck[a], Jo Anne G. Balanay[a], and Terri Johnson[b]

[a]Environmental Health Sciences Program, Department of Health Education and Promotion, East Carolina University, Greenville, North Carolina; [b]Department of Statistics, University of California Los Angeles, Los Angeles, California

ABSTRACT

Groundskeepers spend most of the year working outdoors, exposing them to heat and solar ultraviolet (UV) radiation and increasing their risk to related adverse health effects. Various studies on heat and UV exposures in different occupations have been published, but those on groundskeepers are rare. The purpose of this study was to assess the exposure to heat stress and solar UV radiation among groundskeepers in an eastern North Carolina university setting. Wet bulb globe temperature (WBGT) index using a heat stress monitor and UV effective irradiance (UV_{eff}) index using a digital UV meter were recorded in various work areas three times a day (morning, noon, afternoon) and during three seasons (spring, summer, fall). Data analysis was conducted using descriptive statistics, analysis of variance (ANOVA), Tukey Honestly Significant Difference (HSD), and Pearson Correlation tests. The mean (±SD) WBGT index was the highest in the afternoon (25.4 ± 5.0°C), summer (27.8 ± 3.1°C), and July (29.0 ± 2.6°C); the mean UV_{eff} index was the highest at noon, summer and June (0.0116 ± 0.0061, 0.0101 ± 0.0081, and 0.0114 ± 0.0089 mW/cm^2, respectively). Differences in the mean WBGT and UV_{eff} indices within the time periods of day, seasons and months were significant ($P < 0.01$). The overall correlation between WBGT and UV indices was moderate ($r = 0.42$, $P < 0.01$) but lack of correlation was found during different times of the day during the fall and summer seasons. The largest percentages of WBGT indices exceeding the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs) for different workloads were found in the afternoon (11.3–40.7%), summer (14.6–56%), and July (28.8–76.3%). The mean UV_{eff} for noon (0.0116 mW/cm^2) and afternoon (0.0100 mW/cm^2) exceeded the TLV for 30-min exposure. This study shows that groundskeepers are potentially exposed to excessive heat stress and UV radiation, and are at risk to developing heat- and UV-related illnesses. The study findings will be beneficial in implementing recommended control measures to prevent heat stress and UV exposure among groundskeepers and other similar outdoor workers.

KEYWORDS
Exposure assessment; groundskeeping; heat stress; outdoor workers; ultraviolet radiation

Introduction

Approximately 907,000 workers are employed as landscaping and groundskeeper workers in the United States (U.S.).[1] North Carolina (NC) has an estimated 30,900 workers (3.4% of national employment) and is ranked 8th among the U.S. states with the highest employment in the landscaping and groundskeeping sector.[2] In the southern U.S., groundskeepers work most of the year outdoors, performing physically demanding duties including laying sod, mowing, trimming, planting, fertilizing, watering, raking, digging, maintaining shrubs, trees and lawns, and hardscape construction.[1,3] Since they spend a large amount of work time outdoors, groundskeepers are exposed to heat and solar ultraviolet (UV) radiation, increasing their risk to related adverse health effects.

Excessive heat exposure can cause heat-related illnesses (HRI), ranging from minor (e.g., heat cramps, heat syncope, heat exhaustion) to life-threatening (e.g., heat stroke).[4] Heat stress is associated with a worker's reduced reaction time, reduced ability to focus and increased error rate, hence resulting in increased cognitive performance impairment and risk of occupational injury.[5-7] Heat stress is also linked with kidney disorder and psychological distress.[8,9] Workers are at an increased risk for

CONTACT Jo Anne G. Balanay balanayj@ecu.edu Environmental Health Sciences Program, Department of Health Education and Promotion, East Carolina University, 3407 Carol Belk Building, 300 Curry Ct., Greenville, NC 27858.

HRI because their exposure and response to heat is controlled by job and employer requirements.[10] Nearly 360 occupational heat-related deaths between 2000 and 2010 were identified in the U.S.[11] Approximately 8,300 occupational HRI emergency department (ED) visits and 1,000 inpatient hospitalizations were recorded in the southeastern U.S. from 2007–2011.[12] In NC, HRI symptoms were found to be prevalent among outdoor workers[13,14] and work-related HRI ED visits were more common than non-occupational causes in 19- to 45-year-olds.[15] Specifically, a few OSHA and NIOSH fatality cases due to heat stress involving landscaping workers have been identified, and involved the issuance of OSHA citations to the employer for failure to protect employees from hazards associated with heat stress and to report a workplace fatality.[16-19]

Exposure to solar UV radiation is known as the main cause of skin cancer,[20] and can cause sunburn that may increase the risk of skin cancer.[21] Outdoor workers receive 2–9 times more UV exposure[22] and nearly twofold relative risk of skin cancer compared to indoor workers.[23] Such occupational exposure significantly contributes to their overall UV dose, increasing their risk of skin cancer.[24] Previous studies[25–27] show that various outdoor workers have UV doses exceeding the 0.3 standard erythemal dose (SED) recommended by the International Commission on Non-Ionizing Radiation Protection.[28] Epidemiological evidence shows an increased risk of skin cancer among outdoor workers but skin cancer remains to be rarely recognized as an occupational disease.[24]

Published studies on the heat and UV exposures of groundskeepers are limited. A study by Kearney et al.[29] assessed the knowledge and use of safety equipment and practices, including those for solar UV protection, but UV exposures were not assessed. While other occupational sectors, such as construction,[30–33] agriculture,[30,34-35] and other outdoor workers[26,33,36–39] have been more extensively studied on heat stress and/or UV exposures, to our knowledge, this study is the first of its kind to study both the heat stress and UV exposures of groundskeepers. The subtropical climate in the southeastern region of the U.S. poses the greatest risk on outdoor workers, resulting in a need for reliable surveillance data.[12] A better understanding of the groundskeepers' heat stress and solar UV exposures is essential in developing worker protection programs that are tailored to this occupational group, with the ultimate goal of reducing the risk of heat- and UV-related illnesses and deaths. The purpose of this study was to assess the heat stress and UV radiation exposure of groundskeepers employed in a university setting in eastern NC.

Methods

Monitoring locations

The exposures of groundskeepers to heat stress and solar UVR were assessed by area monitoring. In consultation with the university facilities manager and supervisors, the sampling locations where groundskeepers work were grouped according to the five university areas: (1) East Main Campus (EMC), (2) Central Main Campus (CMC), (3) West Main Campus (WMC), (4) Health Science Campus (HSC), and (5) North Recreational Complex (NRC). The main campus (comprised of EMC, CMC and WMC) covers 410 acres and includes academic, research and recreational facilities, athletic fields, student housing, and parking lots. The HSC covers more than 210 acres and includes academic, research, and medical facilities, the main city hospital, and parking lots. The NRC includes athletic fields, a golf course, ponds and lakes, numerous trees, shrubs, and other plants.

Heat stress monitoring

Heat stress monitoring was conducted in each sampling location using a heat stress monitor (QUESTemp °34, 3M, Oconomowoc, WI), which was placed at a height of 3.5 ft from the ground using a tripod. For each monitoring day, the dry bulb, wet bulb, and globe temperatures (°C), the wet bulb globe temperature (WBGT) index (°C), and relative humidity (%) were recorded after a 30-min stabilization period at three different times of the day: 9 AM (morning), 12 PM (noon), and 3 PM (afternoon). Daily monitoring was conducted during the summer (July to August 2015, June 2016), fall (September to October 2015), and spring seasons (March to May 2016). A total of 453 WGBT indices ($n = 192$ for summer, $n = 104$ for fall, $n = 157$ for spring) were collected during 155 monitoring days throughout the entire study period (Table 1). The WBGT indices were compared to the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) and action limits for heat stress exposure,[40] with consideration of the groundskeepers' work load and work allocation in the monitoring areas.

Ultraviolet (UV) radiation monitoring

UV radiation monitoring was conducted in the same sampling locations as the heat stress monitoring. A digital handheld UV meter (Solarmeter® Model 7.5, Solar Light Co., Inc., Glenside, PA), with spectral response close to the erythemal action spectrum, was used to measure effective irradiance, UV_{eff} (mW/cm^2), of the area's

Table 1. Heat stress and ultraviolet (UV) radiation monitoring schedule and number of readings.

		Heat Stress Monitoring		UVR Monitoring	
Season	Month	Monitoring Days (N)	WBGT Indices (N)	Monitoring Days (N)	UV Indices (N)
Summer	July 2015	20	59	0	0
	Aug 2015	24	68	14	199
	June 2016	22	65	22	259
Fall	Sept 2015	20	58	21	240
	Oct 2015	16	46	18	210
	Nov 2015	0	0	5	60
Spring	March 2016	12	36	12	144
	April 2016	20	60	21	242
	May 2016	21	61	21	243
Total		155	453	134	1,597

UV index by holding the meter at a height of 3.5 ft from the ground. The UV_{eff} indices were recorded at 10-min intervals for 30-min periods (n = 4 per period) that end at three different times of the day: 9 AM (morning), 12 PM (noon), and 3 PM (afternoon). Daily monitoring was conducted during the summer (August 2015, June 2016), fall (September to November 2015), and spring seasons (March to May 2016). A total of 1,597 UV_{eff} indices (n = 458 for summer, n = 510 for fall, n = 629 for spring) were collected during 134 monitoring days throughout the entire study period (Table 1). An activity card was filled out by the investigator for each sampling day to note the location monitored (i.e., outdoor in the sun, outdoor in the shade), weather, task performed, and personal protective equipment (PPE) used by the groundskeeper (if present during monitoring). The average (n = 4) UV_{eff} indices were calculated for each time period of the day (morning, noon, and afternoon) and compared to the ACGIH TLVs for the UV radiation effective irradiance for different daily exposure durations.[40] The maximum exposure time (T_{max}, s) for each average UV_{eff} index was also calculated using the following equation where UV_{eff} is the effective irradiance of UV radiation:[40]

$$T_{max}\,[s] = 0.003\left[J/cm^2\right]/UV_{eff}\left[W/cm^2\right].$$

Data analysis

The mean, median, maximum, and standard deviation for WBGT and UV_{eff} indices by month (March to October), season (spring, summer, fall), and time of day (morning, noon, afternoon) were determined. In addition, the mean, median, maximum, and standard deviation for UV_{eff} indices only by weather condition (sunny, cloudy, rainy) were obtained. Analysis of variance (ANOVA) tests were used to compare mean WGBT and UV_{eff} indices by month, season, time of day, and weather condition (for UV indices only). If a significant difference was found within a category, post hoc analysis was conducted using the Tukey Honestly Significant Difference (HSD) test to compare means between groups and determine which groups differ within each category. Pearson Correlation tests were conducted to determine the strength and direction of linear relationships between WBGT and UV_{eff} indices. The Statistical Package for Social Sciences (SPSS) version 22 (IBM, New York) was used to analyze the data. $P < 0.05$ was considered to be statistically significant.

Results and discussion

WBGT indices

Table 2 compares the WBGT indices by time of day and season. The mean WBGT index was the highest in the afternoon (25.35 ± 5.00°C) and the lowest in the morning (21.40 ± 5.24°C). The mean WBGT indices were significantly different ($F = 26.86$; $df = 2$; $P < 0.01$) by time of day. The mean WBGT index in the morning was significant lower compared to that at noon ($P < 0.01$) and in the afternoon ($P < 0.01$). The highest maximum WBGT index (36.50°C) was measured in the afternoon.

Summer is the season with the highest mean WBGT index (27.76 ± 3.05°C), while spring has the lowest (19.87 ± 5.07°C) (Table 2). The mean WBGT indices were significantly different ($F = 157.14$; $df = 2$; $P < 0.01$) by season. Moreover, each season has a significantly different mean WBGT index compared to the other seasons. The mean WBGT index in the summer is significantly higher ($P < 0.01$) compared to the WBGT indices in the fall (22.75 ± 4.59°C) and spring. Fall also has a significantly higher ($P < 0.01$) mean WBGT index than the spring. Among the seasons, the highest maximum WBGT index (36.50°C) was measured during the summer. However, the mean WBGT index measured in this study for summer months (27.72°C) was lower compared to those found in previous studies on construction workers in Hong Kong (30.6°C)[31] and on outdoor petrochemical industry workers in the Persian Gulf (33.1°C)[41] during the summer.

Table 2. WBGT indices (°C) by time of day and season (N = 453).

Parameter		n	Mean	Median	Maximum	SD
Time of Day	Morning	154	21.40	22.65	30.70	5.24
	Noon	149	24.94	26.00	33.20	5.09
	Afternoon	150	25.35	26.00	36.50	5.00
Season	Spring	157	19.87	20.00	29.40	5.07
	Summer	192	27.76	28.25	36.50	3.05
	Fall	104	22.75	23.05	31.40	4.59

SD – standard deviation

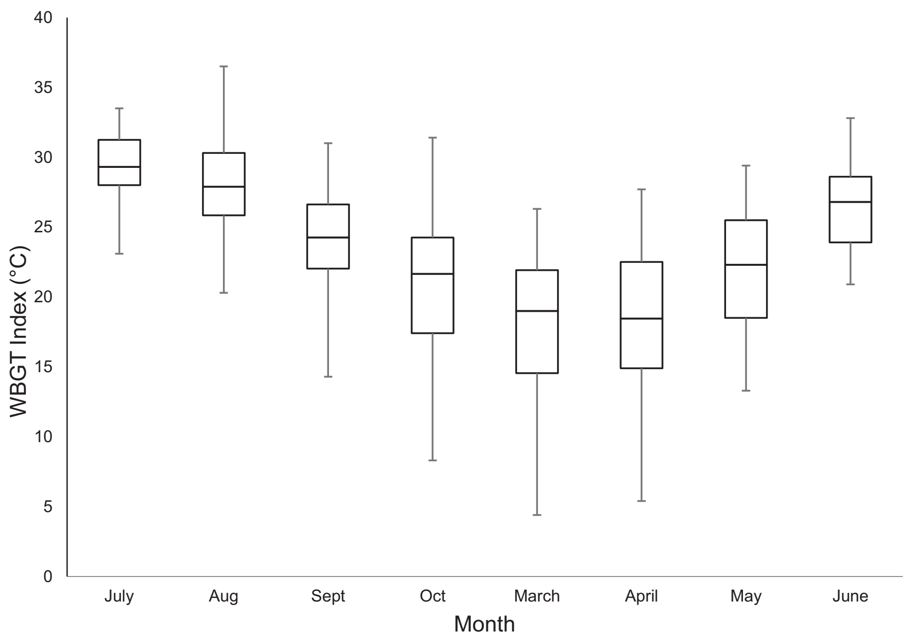

Figure 1. WBGT indices (°C) by month.

The mean and median WBGT index decreased from July to April, and then increased from April to June (Figure 1). July had the highest mean WBGT index (29.00 ± 2.64°C), followed by August (27.83 ± 3.07°C) and June (26.56 ± 2.95°C) (Table 3), which was similar to results in another study conducted in Florence, Italy.[42] March has the lowest mean WBGT index (18.35 ± 4.80°C), followed by April (18.54 ± 5.13°C). The mean WBGT indices were significantly different (F = 58.63; df = 7; P <0.01) by month.

The mean dry bulb, wet bulb, and globe temperatures for the entire study were 20.67 ± 5.09, 24.83 ± 5.89, and 34.52 ± 8.62°C, respectively, with the maximum dry and wet bulb temperatures (29.10 and 36.00°C, respectively) measured during the summer afternoon and the maximum globe temperature (51.00°C) measured during a fall afternoon. The mean relative humidity obtained throughout the study period was 53.0 ± 19.3%, with the minimum (17.0%) recorded during an afternoon of spring season (April), and the maximum (98%) during a morning of fall season (October). By month, the mean relative humidity was highest during September (62.1 ± 19.5%), and lowest during March (40.6 ± 16.9%). By time of day, the mean relative humidity was highest in the morning (67.3 ± 16.6%), and lowest in the afternoon (43.5 ± 17.0%). By season, the mean relative humidity was highest during the fall (58.2 ± 21.7%), and lowest during the spring (49.5 ± 19.8%).

Table 3. WBGT indices (°C) by month (N = 453).

Year	Month	n	Mean	Median	Maximum	SD
2015	July	59	29.00	29.30	33.50	2.64
	August	68	27.83	27.90	36.50	3.07
	September	58	24.15	24.25	31.00	3.53
	October	46	20.99	21.65	31.40	5.17
2016	March	36	18.35	19.00	26.30	4.80
	April	60	18.54	18.45	27.70	5.13
	May	61	22.07	22.30	29.40	4.40
	June	65	26.56	26.80	32.80	2.95

SD – standard deviation

UV indices

Table 4 compares the UV_{eff} by time of day, season, and weather. The mean UV_{eff} was the highest at noon (0.0116 ± 0.0061 mW/cm^2) and the lowest in the morning (0.0014 ± 0.0012 mW/cm^2). The UV_{eff} variability was

Table 4. Ultraviolet (UV) effective irradiance, UV_{eff} (mW/cm^2) by time of day, season and weather (N = 1,597).

Parameter		n	Mean	Median	Maximum	SD
Time of Day	Morning	540	0.0014	0.0010	0.0060	0.0012
	Noon	528	0.0116	0.0110	0.0800	0.0061
	Afternoon	529	0.0100	0.0090	0.0230	0.0057
Season	Spring	629	0.0070	0.0070	0.0230	0.0059
	Summer	458	0.0101	0.0090	0.0800	0.0081
	Fall	510	0.0054	0.0040	0.0190	0.0050
Weather	Sunny	789	0.0101	0.0110	0.0800	0.0070
	Cloudy	732	0.0055	0.0040	0.0260	0.0053
	Rainy	76	0.0021	0.0010	0.0110	0.0026

SD – standard deviation

highest during the afternoon, and least during the morning. The mean UV_{eff} indices were found to be significantly different ($F = 688.91$; $df = 2$; $P < 0.01$) by time of day. The mean UV_{eff} in the morning was significantly lower than that at noon ($P < 0.01$) and in the afternoon ($P < 0.01$). Moreover, the mean UV_{eff} at noon was significantly higher ($P < 0.01$) than that in the afternoon (0.0100 ± 0.0057 mW/cm^2). The highest maximum UV_{eff} (0.0800 mW/cm^2) was measured at noon.

The highest mean UV_{eff} was measured during the summer (0.0101 ± 0.0081 mW/cm^2) and the lowest was measured during the fall season (0.0054 ± 0.0050 mW/cm^2) (Table 4). The UV_{eff} variability was greatest during the summer, and least during the fall. The mean UV_{eff} indices were significantly different ($F = 66.86$; $df = 2$; $P < 0.01$) by season. More specifically, the Tukey HSD test revealed that each season had a significantly different mean UV_{eff} compared to each of the other seasons. The summer had a significantly higher mean UV_{eff} ($P < 0.01$) compared to those in the spring (0.0070 ± 0.0059 mW/cm^2) and fall seasons. Spring had a significantly higher ($P < 0.01$) mean UV_{eff} than the fall. Among the seasons, the highest maximum UV_{eff} (0.0800 mW/cm^2) was measured during the summer, which is similar to that found in a study that measured the UV exposure over various body locations for outdoor workers.[24]

UV_{eff} indices were also determined for three types of weather: sunny, cloudy, and rainy (Table 4). The highest mean UV_{eff} was measured during sunny weather (0.0101 ± 0.0070 mW/cm^2), and the lowest was during rainy weather (0.0021 ± 0.0026 mW/cm^2). The UV_{eff} variability was greatest during sunny weather, and was smallest during the rainy weather. The mean UV_{eff} indices were significantly different ($F = 140.45$; $df = 2$; $P < 0.01$) by weather. The mean UV_{eff} during sunny weather was significantly higher than those during rainy weather ($P < 0.01$) and cloudy weather ($P < 0.01$), while the mean UV_{eff} during cloudy weather was significantly higher than that during rainy weather ($P < 0.01$).

The mean and median UV_{eff} index decreased from August to November 2015, and increased from March to June 2016 (Figure 2). June had the highest mean

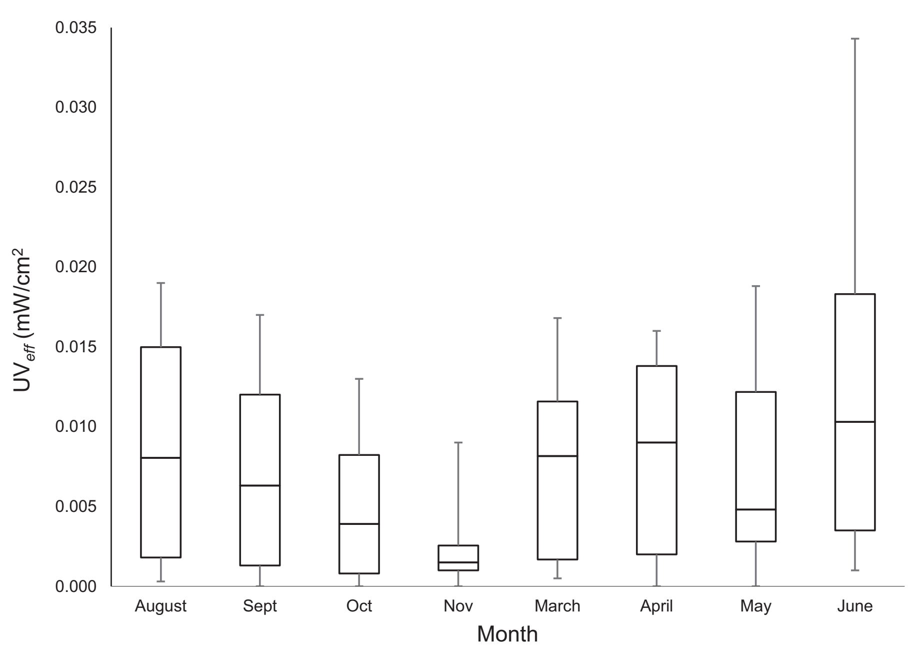

Figure 2. Ultraviolet (UV) effective irradiance, UV_{eff} (mW/cm^2) by month.

Table 5. Ultraviolet (UV) effective irradiance, UV_{eff} (mW/cm^2) by month (N = 1,597).

Year	Month	n	Mean	Median	Maximum	SD
2015	August	199	0.0084	0.0070	0.0230	0.0066
	September	240	0.0067	0.0050	0.0190	0.0057
	October	210	0.0048	0.0040	0.0140	0.0041
	November	60	0.0024	0.0010	0.0090	0.0026
2016	March	144	0.0074	0.0080	0.0180	0.0052
	April	242	0.0081	0.0080	0.0170	0.0059
	May	243	0.0073	0.0050	0.0230	0.0062
	June	259	0.0114	0.0100	0.0800	0.0089

SD – standard deviation

UV_{eff} (0.0114 ± 0.0089 mW/cm^2), followed by August (0.0084 ± 0.0066 mW/cm^2) and April (0.0081 ± 0.0059 mW/cm^2) (Table 5). November had the lowest mean UV_{eff} (0.0024 ± 0.0026 mW/cm^2), followed by October (0.0048 ± 0.0041 mW/cm^2) (Table 5). These findings are similar to those in another published study.[42] The UV_{eff} variability was greatest during the hotter months of June and August, while variability was smallest in November (Figure 2). The mean UV_{eff} indices were significantly different (F = 27.51; df = 7; $P < 0.01$) by month.

Correlation between WBGT and UV_{eff} indices

The correlation between the WBGT and UV_{eff} indices were analyzed to determine if WBGT index can be used as a proxy for UV_{eff}, and vice versa. Overall, the WBGT and UV_{eff} indices have a statistically significant positive correlation ($P < 0.01$), meaning that they tend to increase together (i.e., greater WBGT index is associated with greater UV_{eff}) (Figure 3). The strength of the overall association is approximately moderate ($r = 0.42$; $0.3 < r < 0.5$). When analyzed by time period of the day, the correlation is still significant ($P < 0.01$) for morning ($r = 0.35$), noon ($r = 0.24$) and afternoon ($r = 0.36$), but the strength of the correlation became weak for the noon-time observations. By season, the correlation is still significant ($P < 0.01$) for spring ($r = 0.48$), summer ($r = 0.35$), and fall ($r = 0.45$), with summer having the weakest correlation. The WBGT and UV_{eff} indices are still significantly correlated when analyzed by month ($P < 0.01$ to $P = 0.01$), with May having the strongest correlation ($r = 0.66$) and August having the lowest correlation ($r = 0.35$) between the indices. A study conducted in Italy similarly showed an association between outdoor heat stress and UV exposure, wherein probabilities of UV-induced risk of erythema were significantly higher on days with heat stress conditions compared to those on days when heat discomfort did not occur.[42] However, the correlation in the previous study was found to be strong as compared to being moderate in our study.

Further correlation analysis of WBGT and UV_{eff} indices by time of day and season showed unexpected results wherein moderate positive correlation ($P < 0.01$) was found only in the morning ($r = 0.36$), noon ($r = 0.36$), and afternoon ($r = 0.42$) of the spring season (Figure 4). The correlation at different times of the day during the fall ($r = 0.24$ to 0.03; $P = 0.06$ to 0.86) and summer seasons ($r = -0.18$ to 0.18; $P = 0.27$ to 0.41) were not statistically significant. These findings show that WBGT index may not be a good proxy for UV_{eff} and, thus, not a good indicator of UV exposure during the summer and fall

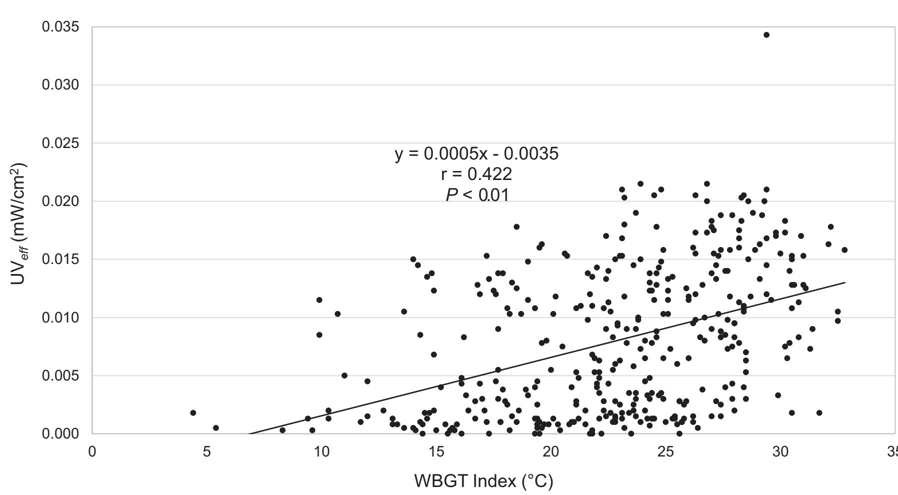

Figure 3. Overall correlation between WBGT indices (°C) and UV effective irradiance, UV_{eff} (mW/cm^2).

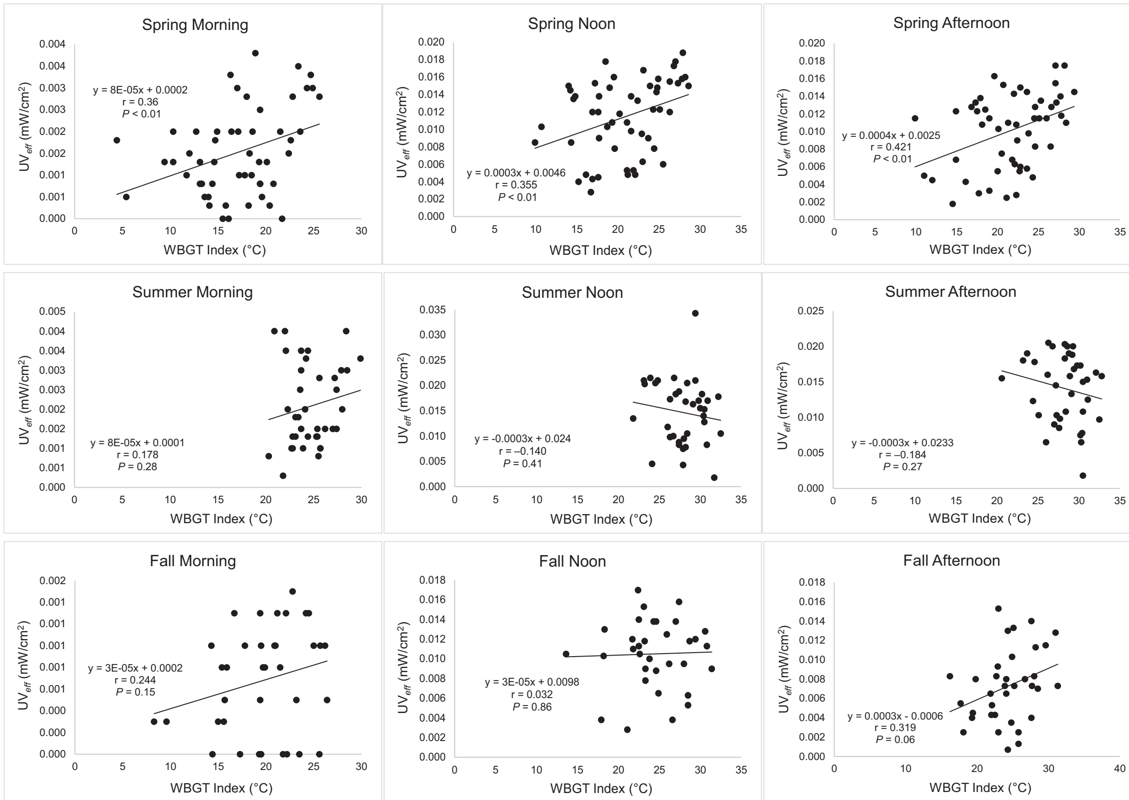

Figure 4. Correlation between WBGT indices (°C) and UV effective irradiance, UV_{eff} (mW/cm^2) by season and time of day.

seasons. The use of WBGT index as a substitute for UV_{eff} may result to either a false alarm for high UV exposure (i.e., WBGT index is high when UV_{eff} is low) or a false sense of safety (i.e., WBGT index is low when UV_{eff} is high). This is particularly dangerous during the cooler fall season when low heat stress conditions may be mistakenly assumed to have low UV exposures, potentially exposing groundskeepers to excessive UV radiation.

Comparison with ACGIH TLVs and action limits

WBGT indices

The ACGIH TLV and action limit for heat stress exposure considers the metabolic rate (as related to workload) based on work activities (light, moderate, heavy, very heavy) and the allocation of work in a cycle of work and recovery (0–25%, 25–50%, 50–75%, 75–100%).[40] Based on example activities in the ACGIH guidelines on metabolic rate categories,[40] light work conducted by the groundskeepers included the operation of riding mowers and sweepers; moderate work included placing recycling and trash cans for events, planting shrubs and flowers, weed eating, edging, and routine trash pick-up; heavy work included laying mulch, tree and shrub trimming, bleacher set-up, and operation of backpack blowers and sprayers. These identified tasks are based on observations during monitoring throughout the study. Work allocation based on 2-hr work/recovery cycles was calculated to be within the 50–75% category, considering the groundskeepers' work hours (7:30 AM to 4:30 PM) and break schedule (lunch from 12:00 PM to 1:00 PM; 15-min breaks each at 9:00 AM and 2:00 PM). The TLV and action limit for the "50–75%" work allocation is 31.0°C and 28.5°C for light work, 29.0°C and 26.0°C for moderate work, and 27.5°C and 24.0°C for heavy work, respectively.

There were several days when groundskeepers were not observed working in the vicinity of the monitored site for some or all of the monitored time periods of the day. Thus, the TLV for the actual work conducted cannot be determined but it can be assumed for each workload category. Table 6 shows the estimated number and percentage of WBGT indices that may potentially exceed the corresponding ACGIH TLV and action limits by time of day, season and month, assuming three different workload categories. For the time of day, the morning had potentially the least percentage of WBGT indices exceeding the TLVs for light (0.0%), moderate (4.5%), and heavy (11.0%) workloads, while the afternoon had potentially the largest percentage of WBGT indices exceeding the TLVs for light (11.3%), moderate (27.3%), and heavy (40.7%) workloads.

Table 6. Estimated number and percentage of WBGT indices exceeding ACGIH TLV* and action limit* for heat stress exposure by time of day and season based on workload assumptions.

		Light Workload				Moderate Workload				Heavy Workload			
		>TLV		>AL		>TLV		>AL		>TLV		>AL	
Parameter	No. of Days	n	%	n	%	n	%	n	%	n	%	n	%
Time of Day													
Morning	154	0	0.0	11	7.1	7	4.5	27	17.5	17	11.0	57	37.0
Noon	149	13	8.7	40	26.8	37	24.8	74	49.7	56	37.6	91	61.1
Afternoon	150	17	11.3	45	30.0	41	27.3	74	49.3	61	40.7	97	64.7
Season													
Spring	157	0	0.0	2	1.3	1	0.6	19	12.1	9	5.7	37	23.6
Summer	192	28	14.6	86	44.8	77	40.1	132	68.8	108	56.3	164	85.4
Fall	104	2	1.9	8	7.7	7	6.7	24	23.1	17	16.3	44	42.3
Month													
March	36	0	0.0	0	0.0	0	0.0	1	2.8	0	0.0	3	8.3
April	60	0	0.0	0	0.0	0	0.0	4	6.7	1	1.7	10	16.7
May	61	0	0.0	2	3.3	1	1.6	14	23.0	8	13.1	24	39.3
June	65	4	6.2	16	24.6	14	21.5	36	55.4	27	41.5	48	73.8
July	59	17	28.8	40	67.8	34	57.6	47	79.7	45	76.3	56	94.9
Aug	68	7	10.3	29	42.6	28	41.2	49	72.1	36	52.9	60	88.2
Sept	58	0	0.0	6	10.3	5	8.6	17	29.3	12	20.7	30	51.7
Oct	46	2	4.3	2	4.3	2	4.3	7	15.2	5	10.9	14	30.4

TLV – threshold limit value; AL – action limit
*ACGIH TLV and AL for work allocation in work/recovery cycle of 50–75%

Among the seasons, spring had the smallest percentages of TLV exceedance for light (0.0%), moderate (0.6%), and heavy (5.7%) workloads, and summer had the largest percentages for the workload categories (14.6%, 40.1%, and 56.3%, respectively). These findings indicate that workers have the highest risk of HRI in the afternoon and during the summer, particularly when performing moderate and heavy workloads. Performing light workload at noon and afternoon may still result in heat stress conditions that would exceed the TLV.

Among the months monitored, July has the highest percentages of TLV exceedances for each workload category (28.8% for light, 57.6% for moderate, 76.3% for heavy), followed by August (10.3% for light, 41.2% for moderate, 52.9% for heavy) and June (6.2% for light, 21.5% for moderate, 41.5% for heavy) (Table 6). No TLV exceedances were observed during March, while a TLV exceedance of 1% for heavy workload only was observed during April.

Moreover, percentages of WBGT indices exceeding action limits for various workloads range from 7.1–37.0% for morning, 26.8–61.1% for noon, and 30.0–64.7% for afternoon among the times of the day, and range from 1.3–23.6% for spring, 7.7–42.3% for fall, and 44.8–85.4% for summer among the seasons monitored (Table 6). Exceeding the action limits indicate that workers are in conditions in which a heat stress management program should be considered. Results show that there may be a need to implement preventive measures to protect workers from HRI even during the time of day (i.e., morning) and the season (i.e., spring) with the lowest risk of heat stress, regardless of the workload. Recommended control measures include preferably scheduling heavy work during the morning period, and light work during hotter times of the day (noon and afternoon) and hotter months (June to August) if possible; taking more frequent breaks during hotter times of the day and hotter months; taking work breaks in a cool and shaded area; and ensuring that groundskeepers have access to and have sufficient intake of hydrating fluids. These preventive measures are consistent with the recommendations given by OSHA as part of its summer campaign to prevent heat-related illnesses and fatalities among outdoor workers.[43,44]

UV_{eff} indices

UV_{eff} indices were measured over a 30-min period in 10-min increments, and the average ($n = 4$) was calculated for each time period of the day (morning, noon, afternoon) for comparison with the ACGIH TLV for the UV radiation effective irradiance for 30 min and other daily exposure durations.[40] The TLV for 30-min daily exposures is 0.0017 mW/cm^2 and was used to compare these time-of-day average UV_{eff} indices to determine if groundskeepers exceed this exposure limit. However, certain outdoor tasks performed by groundskeepers may last for more than 30 min (e.g., mowing for 2 hr or more) and, thus, three other daily exposure durations (2, 4, and 8 hr) were used to assume potential work exposure scenarios and to determine if corresponding TLVs (0.0004, 0.0002, and 0.0001 mW/cm^2, respectively) were exceeded given the measured UV_{eff} indices.

The overall mean UV_{eff} for the morning (0.0014 mW/cm^2) was below the TLV for 30-minute exposure, while those for noon (0.0116 mW/cm^2) and afternoon

Table 7. Number and percentage of ultraviolet (UV) effective irradiance, UV_{eff}, exceeding ACGIH TLV* for different daily UV exposure periods by time of day, season, and month.

Parameter	No. of Days	30 min		2 hr		4 hr		8 hr	
		N	%	n	%	n	%	n	%
Time of Day									
Morning	135	43	31.9	112	83.0	121	89.6	121	89.6
Noon	134	131	97.8	133	99.3	133	99.3	133	99.3
Afternoon	135	128	94.8	134	99.3	134	99.3	134	99.3
Season									
Spring	159	128	80.5	151	95.0	155	97.5	155	97.5
Summer	115	97	84.3	114	99.1	115	100.0	115	100.0
Fall	130	77	59.2	114	87.7	118	90.8	118	90.8
Month									
March	36	27	75.0	36	100.0	36	100.0	36	100.0
April	61	49	80.3	57	93.4	58	95.1	58	95.1
May	62	52	83.9	58	93.5	61	98.4	61	98.4
June	65	59	90.8	65	100.0	65	100.0	65	100.0
Aug	50	38	76.0	49	98.0	50	100.0	50	100.0
Sept	61	40	65.6	56	91.8	56	91.8	56	91.8
Oct	54	32	59.3	44	81.5	48	88.9	48	88.9
Nov	15	5	33.3	14	93.3	15	100.0	15	100.0

*TLV – threshold limit value; 0.0017 mW/cm^2 (30 min), 0.0004 mW/cm^2 (2 hr), 0.0002 mW/cm^2 (4 hr), 0.0001 mW/cm^2 (8 hr)

(0.0100 mW/cm^2) exceeded the TLV. Moreover, all the overall mean UV_{eff} indices for all seasons and months monitored exceeded the TLV for 30-min exposure.

Table 7 shows the estimated number and percentage of time-of-day mean UV_{eff} indices that may potentially exceed the corresponding ACGIH TLV by time of day, season, and month, assuming four different daily UV exposure periods (30 min, 2 hr, 4 hr, and 8 hr). For the time of day, the morning had potentially the least percentage of UV_{eff} exceeding the TLVs for 30-min (31.9%), 2-hr (83.0%), 4-hr (89.6%), and 8-hr (89.6%) exposure periods, though these exceedance percentages are still relatively high; both noon and afternoon had similar large percentages of UV_{eff} exceeding the TLVs, reaching at least 98% for all exposure periods. Among the seasons, summer had the biggest percentages of TLV exceedance for all exposure periods (ranging from 84.3–100%), while fall had the smallest percentages (ranging from 59.2–90.8%). These findings indicate that workers have the highest risk of UV-related illnesses (e.g., erythema, photokeratitis) at noon or afternoon and during the summer, particularly when exposed to UV radiation for several hours. However, working outdoors under the sun in the morning and during the cooler seasons (spring and fall) may still result in UV exposures that would exceed the TLV. Among the months monitored, June has the highest percentages of TLV exceedances for each exposure period (90.8% for 30-min exposure, and 100% for 2-hr, 4-hr, and 8-hr exposures) (Table 7). TLV exceedances for all daily exposure periods were observed on all months monitored, although at different extents, which indicates that preventive measures for UV exposure among groundskeepers must be implemented throughout the year.

The maximum exposure times (T_{max}) calculated for the UV_{eff} measured range from 12.5 min – 2.8 hr in the morning, 1.5–50 min at noon, and 2.5 min–1.7 hr in the afternoon by time of day; and range from 2.7 min–2.8 hr during spring, 1.5 min–2.8 hr during summer, and 2.9 min–2.8 hr during fall by season. Among the months monitored, June had the lowest maximum exposure times recommended (ranging from 1.5–50 min) due to the highest measured UV indices during this month. Considering that no calculated T_{max} exceeded 2.8 hr, groundskeepers are recommended to work outdoors for less than 3 hr, regardless of the time of day, season, or month.

Based on these findings, recommendations to prevent solar UV exposure among groundskeepers include limiting exposure time, particularly during sunny days, in the noon or afternoon, and during the summer; rescheduling outdoor work that lasts for more than an hour to the morning, if possible; taking breaks in a shaded area; and using appropriate clothing (e.g., long sleeves, tightly woven dark-colored clothing), wide brim hats, and sunscreen with ≥ sun protection factor (SPF) 15 while working outdoors during any month, especially at noon and afternoon. These preventive measures are consistent with the recommendations given by OSHA,[45] NIOSH,−[46] and others[21,47] to protect workers from the harmful effects of UV exposure. However, it must be noted that the use of tightly woven dark-colored clothing may lead to an increase in thermal load to the worker and, thus, increasing the potential for HRI. Caution must be exercised if both UV and heat stress exposures are present (e.g., during summer season).

Strengths and limitations

The main strengths of this study are the large amount of data collected for WBGT and UV_{eff} indices, and the rarity of these exposure data for groundskeepers. Moreover, due to the simultaneous measurement of most of the WBGT and UV_{eff} indices collected, determining the correlation between these two indices was made possible, which was rarely done in the published literature.

One limitation identified in the study is the use of area monitoring in assessing UV radiation exposure instead of personal monitoring due to budget constraints and lack of available personal UV meters. Personal monitoring during the performance of actual tasks by groundskeepers (e.g., during mowing or the use of weed eaters) would provide a better estimation of the workers' actual UV exposure and may require less assumptions (e.g., exposure time) regarding their exposure assessment. Another limitation is that some months were not represented during the monitoring due to time constraints and unavailability of instruments during those times. WBGT indices were not collected during the months of January, February, November, and December, while UV_{eff} indices were not collected in January, February, July, and December. Most of these months excluded in the monitoring were cold months, and may not matter in heat stress monitoring but may result in data gaps in UV monitoring since UV exposure seems to be significant throughout the year despite the cold temperature.

Summary and conclusions

Groundskeepers are exposed to heat stress and solar ultraviolet (UV) radiation due to the outdoor nature of their work. Mean WBGT indices were found to be highest in the afternoon among the times of the day, during the summer among the seasons, and in July among the months monitored, while mean UV_{eff} indices were highest at noon, during the summer, and in June. The WBGT and UV_{eff} indices were positively correlated ($P < 0.01$), with moderate strength of association ($r = 0.42$), but lack of correlation was demonstrated when analyzed by different times of day during the fall and summer seasons. The groundskeepers were found to work outdoors during times of the day and year with high WBGT indices that exceed the ACGIH threshold limit values (TLVs) for various workload categories (i.e., light, moderate, heavy), and with high UV_{eff} indices that exceed the TLV for various daily exposure periods (30 min, 2 hr, 4 hr, 8 hr). Findings show that groundskeepers have the highest risk of HRI in the afternoon and during the summer when workload is moderate or heavy, and have the highest risk of UV-related illnesses at noon or afternoon and during the summer when exposed to UV radiation for several hours.

This study has demonstrated the need to implement effective heat stress management and solar UV exposure prevention programs for university groundskeepers to decrease their risk of developing heat-related and UV-related adverse health effects through task-appropriate preventive measures. Heat stress among groundskeepers may be reduced to acceptable levels by the scheduling of heavy workload during the cooler times of the day (i.e., morning) and year (i.e., spring or fall season), and of light workload during the hotter times of the day (i.e., noon or afternoon) and year (i.e., summer); more frequent work breaks in cool and shaded areas, particularly during hotter periods of the day and year; provision of sufficient hydrating fluids; and annual training of workers on heat stress management. UV exposure among groundskeepers may be reduced by limiting exposure time outdoors in the sun (e.g., less than 3 hr daily), particularly during hotter periods of the day and year; taking work breaks in shaded areas; using personal solar UV protection (e.g., long-sleeved shirt, wide brim hat, sunscreen with ≥SPF 15); and implementing all these preventive measures throughout the year. The study findings will also be useful in developing evidence-based training materials that are relevant to the groundskeepers.

The heat stress and solar UV exposure of groundskeepers in this study may be unique to those working in the university setting (considering workload and work/recovery cycle) and in this particular geographic location (i.e., southeastern U.S.), and may not be representative of those in other workplaces (e.g., commercial setting) and geographic locations due to differences in various factors (e.g., workload and work/recovery cycle, specific groundskeeper tasks, climate). Further investigating the relationship of these factors to heat stress and UV exposures will be beneficial. The actual use of personal protection by the workers against heat stress and UV exposure during the workday was not fully assessed in this study and must also be investigated in future research. Future studies on similar research areas could be improved by conducting heat stress and solar UV monitoring throughout the groundskeepers' work shift to determine the actual workload corresponding to the measured WBGT indices and the actual number of hours the workers spend outside working at UV_{eff} indices exceeding the TLV, and by using wearable personal UV monitoring devices to measure the amount of personal UV exposure received throughout the work shift.

Acknowledgments

The authors would like to thank Mr. John Gill and all facilities supervisors for their cooperation and support, and to all groundskeepers who assisted in the conduct of this study. We appreciate the helpful comments of two anonymous reviewers that added value to the manuscript.

Funding

This study was supported by Grant #2T42OH008436 from the National Institute for Occupational Safety and Health (NIOSH). Its contents are solely the responsibility of the authors and do not necessarily represent the official views of NIOSH.

References

[1] **Bureau of Labor Statistics (BLS)**: *Occupational Employment Statistics: Occupational Employment and Wages, May 2016: 37–3011 Landscaping and Groundskeeping Workers*. Washington, DC: U.S. Department of Labor, 2016. Available at http://www.bls.gov/oes/current/oes373011.htm (accessed July 11, 2017).

[2] **Bureau of Labor Statistics (BLS)**: *May 2016 State Occupational Employment and Wage Statistics, North Carolina*. Washington, DC: U.S. Department of Labor, 2016. Available at https://www.bls.gov/oes/current/oes_nc.htm (accessed July 11, 2017).

[3] **Occupational Safety and Health Administration (OSHA)**: *Safety and Health Topics: Landscaping and Horticultural Services*. Washington, DC: OSHA, U.S. Department of Labor. Available at https://www.osha.gov/SLTC/landscaping/index.html (accessed July 5, 2017).

[4] **Larrañaga, M.D.**: Applied Physiology of Thermoregulation and Exposure Control, Chapter 27. In *The Occupational Environment – Its Evaluation, Control, and Management*, 3rd ed., D.H. Anna (ed.). Fairfax, VA: American Industrial Hygiene Association, 2011. pp. 892–893.

[5] **Baker, B., and J. Ladue**: How heat stress affects performance. *Environ. Health Today 3(6)*:45–48 (2010).

[6] **Tawatsupa, B., V. Yiengprugsawan, T. Kjellstrom, J. Berecki-Gisolf, S.-A. Seubsman, and A. Sleigh**: Association between heat stress and occupational injury among Thai workers: findings of the Thai Cohort Study. *Ind. Health 51(1)*:34–46 (2013).

[7] **Mazlomi, A., F. Golbabaei, S.F. Dehghan, et al.**: The influence of occupational heat exposure on cognitive performance and blood level of stress hormones: A field study report. *Int. J. Occup. Saf. Ergon. 23*(3):431–439 (2017).

[8] **Tawatsupa, B., L.L.-Y. Lim, T. Kjellstrom, S.-A. Seubsman, and A. Sleigh**: The association between overall health, psycological distress, and occupational heat stress among a large national cohort of 40,913 Thai workers. *Global Health Action 3*:5034 (2010).

[9] **Tawatsupa, B., L.L.-Y. Lim, T. Kjellstrom, S.-A. Seubsman, and A. Sleigh**: Association between occupational heat stress and kidney disease among 37,816 workers in the Thai Cohort Study (TCS). *J. Epid. 22(3)*:251–260 (2012).

[10] **Roelofs, C., and D. Wegman**: Workers: The climate canaries. *Am. J. Public Health 104*(10):1799–1801 (2014).

[11] **Gubernot, D.M., G.B. Anderson, and K.L. Hunting**: Characterizing occupational heat-related mortality in the United States, 2000–2010: An analysis using the census of fatal occupational injuries database. *Am. J. Ind. Med. 58*:203–211 (2015).

[12] **Morano, L.H., T.L. Bunn, M. Lackovic, et al.**: Occupational health-related illness emergency department visits and inpatient hospitalizations in the southeastern region, 2007–2011. *Am. J. Ind. Med. 58*:1114–1125 (2015).

[13] **Arcury T.A., P. Summers, J.W. Talton, H., et al.**: Heat illness among North Carolina Latino farmworkers. *J. Occup. Environ. Med. 57(12)*:1299–1304 (2015).

[14] **Kearney, G.D., H. Hu, X. Xu, M.B. Hall, and J.G. Balanay**: Estimating the prevalence of heat-related symptoms and sun safety-related behavior among Latino farmworkers in Eastern North Carolina. *J. Agromed. 21*(1):15–23 (2016).

[15] **Rhea, S., A. Ising, A.T. Fleischauer, L. Deyneka, H. Vaughan-Batten, and A. Waller**: Using near real-time morbidity data to identify heat-related illness prevention strategies in North Carolina. *J. Commun. Health* 37(2):495–500 (2012).

[16] **National Institute for Occupational Safety and Health (NIOSH)**: *Landscape Mowing Assistant Dies from Heat Stroke*. Atlanta, GA: U.S. Centers for Disease Control and Prevention, 2002. Available at http://www.cdc.gov/niosh/face/stateface/mi/02mi075.html (accessed July 11, 2017).

[17] **Occupational Safety & Health Administration (OSHA)**: *Accident: 202443289 – Employee Dies from Heat Stress*. Washington, DC: U.S. Department of Labor, 2006. Available at https://www.osha.gov/pls/imis/accidentsearch.accident_detail?id=202443289 (accessed July 11, 2017).

[18] **Occupational Safety and Health Administration (OSHA)**: *Accident: 202463477 – Employee Dies after Cutting Grass*. Washington, DC: U.S. Department of Labor, 2006. Available at https://www.osha.gov/pls/imis/accidentsearch.accident_detail?id=202463477 (accessed July 11, 2017).

[19] **Occupational Safety and Health Administration (OSHA)**: *Accident: 200515427 – Employee Collapses from Heat Exhaustion, Later Dies*. Washington, DC: U.S. Department of Labor, 2011. Available at https://www.osha.gov/pls/imis/accidentsearch.accident_detail?id=200515427 (accessed July 11, 2017).

[20] **Armstrong, B.K., and A. Kricker**: The epidemiology of UV induced skin cancer. *Photochem. Photobiol. B. 63*:8–18 (2001).

[21] **Glanz, K., D.B. Buller, and M. Saraiya**: Reducing ultraviolet radiation exposure among outdoor workers: State of the evidence and recommendations. *Environ. Health J. 6*:22–29 (2007).

[22] **Godar, D.E.**: UV doses worldwide. *Photochem. l. 81*:736–749 (2005).

[23] **Schmitt, J., A. Seidler, T.L. Diepgen, and A. Bauer A**: Occupational ultraviolet light exposure increases the risk for the development of cutaneous squamous cell carcinoma: A systematic review and meta-analysis. *Br. J. Dermatol. 164*:291–307 (2011).

[24] **Milon, A., J.-L. Bulliard, L. Vuilleumier, B. Danuser, and D. Vernez**: Estimating the contribution of occupational solar ultraviolet exposure to skin cancer. *Brit. J. Dermatol. 170*:1157–1164 (2014).

[25] **Vishvakarman, D., J.C.F. Wong, and B.W. Boreham**: Annual occupational exposure to ultraviolet radiation in Central Queensland. *Health Phys. 81*:536–544 (2001).

[26] **Thieden, E., S.M. Collins, P.A. Philipsen, G.M. Murphy, and H.C. Wulf**: Ultraviolet exposure patterns of Irish and Danish gardeners during work and leisure. *Br. J. Dermatol. 153*:795–801 (2005).

[27] **Hammond, V., A.I. Reeder, and A. Gray**: Patterns of real-time occupational ultraviolet radiation exposure among a sample of outdoor workers in New Zealand. *Publ. Health 123*:182–187 (2009).

[28] **International Commission on Non-ionizing Radiation Protection (ICNIRP)**: Guidelines on limits of exposure to ultraviolet radiation of wavelengths between 180 nm and 400 nm (incoherent optical radiation). *Health Phys. 87*:171–186 (2004).

[29] **Kearney, G.D., X. Xu, A. Hight, and T. Arcury**: Behavior and perception of using safety gear among commercial landscapers: a pilot study. *J. Occup. Environ. Hyg. 10*:D79–D85 (2013).

[30] **Morioka, I., N. Miyai, and K. Miyashita**: Hot environment and health problems of outdoor workers at a construction site. *Ind. Health 44*:474–480 (2006).

[31] **Chan, A.P., M.C. Yam, J.W. Chung, and Y. Wen**: Developing a heat stress model for construction workers. *J. Facil. Manage. 10(1)*:59–74 (2012).

[32] **Chan A.P.C., W. Yi, D.W.M. Chan, and D.P. Wong**: Using the thermal work limit as an environmental determinant of heat stress for construction workers. *J. Manage. Eng. 29(4)*:414–423 (2013).

[33] **Golbabaei, F., M.R.A. Shendi, M.R. Monazzam, M. Hosseini, and M. Yazdani avval**: Investigation of heat stress based on WBGT index and its relationship with physiological parameters among outdoor workers of Shabestar city. *J. Health Saf. Work 5(2)*: 85–94 (2015).

[34] **Spector, J.T., J. Krenz, E. Rauser, and D.K. Bonauto**: Heat-related illness in Washington State Agriculture and Forestry Sectors. *Am. J. Ind. Med 57*:881–895 (2014).

[35] **Spector, J.T., D.K. Bonauto, L. Sheppard, et al.**: A case-crossover study of heat exposure and injury risk in outdoor agricultural workers. *PLoS One 11(10)*:1–16 (2016).

[36] **Dehghan, H., S. Mortazavi, M. Jafari, M. Maracy, and M. Jahangiri**: The evaluation of heat stress through monitoring environmental factors and physiological responses in melting and casting industries workers. *Int. J. Environ. Health Eng. 1(1)*:21 (2012).

[37] **Vatani, J., F. Golbabaei, S.F. Dehghan, and A. Yousefi**: Applicability of Universal Thermal Climate Index (UTCI) in occupational heat stress assessment: A case study in brick industries. *Ind. Health 54*:14–19 (2016).

[38] **Venugopal, V., J.S. Chinnadurai, R.A.I. Lucas, and T. Kjellstrom**: Occupational heat stress profiles in selected workplaces in India. *Int. J. Environ. Res. Public Health 13*(1):1–13 (2016).

[39] **Razdi, I., N. Roni, and N.F. Din**: Heat strain and work performance among traffic police officers in Kuala Lumpur. *Ann. Trop. Med. Public Health 10*:65–70 (2017).

[40] **American Conference of Governmental Industrial Hygienists (ACGIH)**: *2017 TLVs® and BEIs®*. Cincinnati, OH: ACGIH, 2017.

[41] **Dehghan, H., S.B. Mortazavi, M.J. Jafari, and M.R. Maracy**: Evaluation of wet bulb globe temperature index for estimation of heat strain in hot/humid conditions in the Persian Gulf. *J. Res. Med. Sci. 17(12)*:1108–1113 (2012).

[42] **Morabito M., D. Grifoni, A. Crisci, et al.**: Might outdoor heat stress be considered a proxy for the unperceivable effect of the ultraviolet-induced risk of erythema in Florence? *J. Photochem. Photobiol. B 130*:338–348 (2014).

[43] **Occupational Safety and Health Administration (OSHA)**: *Using the Heat Index: A Guide for Employers*. Washington, DC: OSHA, U.S. Department of Labor. Available at https://www.osha.gov/SLTC/heatillness/heat_index/pdfs/all_in_one.pdf (accessed July 11, 2017).

[44] **Occupational Safety and Health Administration (OSHA)**: *Heat Illness Prevention Campaign: Water. Rest. Shade. OSHA's Campaign to Keep Workers Safe in the Heat*. Washington, DC: OSHA, U.S. Department of Labor. Available at https://www.osha.gov/heat/index.html (accessed July 11, 2017).

[45] **Occupational Safety & Health Administration (OSHA)**: *Protecting Yourself in the Sun*. Washington, DC: OSHA, U.S. Department of Labor, 2003. Available at https://www.osha.gov/Publications/OSHA3166/osha3166.html (accessed July 11, 2017).

[46] **National Institute for Occupational Safety and Health (NIOSH)**: *Sun exposure – Recommendations*. Atlanta, GA: U.S. Centers for Disease Control and Prevention, 2016. Available at https://www.cdc.gov/niosh/topics/sunexposure/recommendations.html (accessed July 11, 2017).

[47] **Oh, S.S.**: Validating outdoor workers' self-report of sun protection. *Prev. Med. 39*:798–803 (2004).