Nigerian Research Journal of Engineering and Environmental Sciences 6(1) 2021 pp. 398-404

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Effect of Solar Radiation on Human Response during Block Laying in Ogun State, Nigeria

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ARTICLE INFORMATION

Article history:
Received 20 Feb, 2021
Revised 15 Apr, 2021
Accepted 22 Apr, 2021
Available online 30 Jun, 2021

Keywords:
Solar radiation
Meteorological
Physiological
Temperature
Blocklaying
Mason
Outdoor

ABSTRACT

Considerable numbers of outdoor workers worldwide are exposed to solar radiation and this exposure induces various adverse health effects on the workers. This study was conducted to determine the effect of solar radiation on human response during block laying in Ogun State, Nigeria. Two hundred and four masons performing block laying in outdoor environment were investigated between January and December. The meteorological parameters were measured and recorded around the mason which included the air temperature, relative humidity, wind speed, solar radiation and radiant temperature respectively. Similarly, physiological parameters of the mason were also measured and recorded such as skin and core temperature. The results showed that the mean value of 33.13±2.34 ^{o}C, 55.32±6.40, 0.48±0.03 m/sec, 662.73±100.31 w/m^2 and 34.00±2.13 ^{o}C were observed for air temperature, relative humidity, wind speed, solar radiation and radiant temperature respectively. The result also revealed that the mean skin and core temperature of the mason were 34.02±0.54 ^{o}C and 36.39±0.14 ^{o}C respectively. The study concluded that the combination of high temperature and high relative humidity serves to reduce the thermal comfort of the mason and outdoor air quality.

1. INTRODUCTION

The contribution of solar radiation to the global thermal comfort and local thermal condition of a person is considered as very important. For many years, solar radiation and human health have been the focus of discussions both in conferences and journals worldwide, within the field of photo-biophysics (Antoniadis et al., 2020). The focus on the topic is no doubt, that several health effects of solar exposure have recently been revealed. The thermal environment indices adverse effects on human health, affecting psychological responses and cardiovascular functions and increasing human mortality (Morabito et al., 2014) Delineation of these effects, looking for common causes and balancing them against the risks will be further researched (Juzeniene et al., 2011). Furthermore, there is extremely increasing interest in solar radiation and health among common people, hence, the new knowledge is rapidly diffusing into the public. Modenese et al. (2018) reported that 95% of the solar radiation on the Earth's surface is composed by infrared and visible wavelengths, at about 45% and 50%, respectively; whereas ultraviolet accounts for approximately 5%. Nevertheless, ultraviolet ray is able to induce the main and most severe adverse health effects on humans, and is responsible for the classification of solar radiation (Modenese et al., 2018). Juzeniene et al. (2011) reported that solar radiation has an important influence, not only on physical health, but also on psychological conditions and mental health. The characteristic of solar radiation should be considered for the aspects of spectral content and directional properties although radiant temperatures can be used for both indoor and outdoor thermal environments. The effect of radiation in the environment can be dangerous and fatal to humans and animals. The damage it causes depends on the level of radiation and the resilience of the organism (Modenese et al., 2018).

The solar radiation spectrum at the Earth's surface is quite different from that emitted by the Sun due to the shielding effect of various atmospheric components (Musa 2016). Ozone is particularly important as it filters out all the wavelengths shorter than 290 nm (Modenese et al., 2018). Both environmental and individual factors influence acute and long-term (cumulative) solar ultraviolet exposure of outdoor workers. Agarwal (2017) reported that work organization may require workers to perform their activities during the central hours of the day and/or during the hottest seasons, as usually happens in the construction sector. Similarly, working posture is relevant in determining the body areas with the highest exposures in construction, where different working tasks or the activity of a mason compared to the activity of other profession may respectively induce a high exposure of the face and chest or the back.

Outdoor work is particularly relevant in influencing cumulative exposure, with possible photochemical damage accumulating in the skin and eyes of the workers for many years, finally resulting in adverse effects. European Agency for Safety and Health at Work described outdoor work as exposed to solar radiation for at least the 75% of their working time, which includes anon-exhaustive list of activities: farmers, silviculturists and horticulturists, farm workers, commercial garden and park workers, postmen and sorters, newspaper delivery workers, physical education instructors, trainers, coaches, and childcare workers (Agarwal 2017). Variation in ozone transmittance with attitude in atmosphere for radiation in the 9.6 mm absorption band was studied using Goody model on the data comprising of pressure and temperature at different altitudes (0-26 km) for three months of January, February and March 2019 in Lagos southwest Nigeria (Sowole, 2020) The main objective of this study is to determine the effects of solar radiation exposure risk of outdoor workers performing block laying activities in and outdoor environment and adverse health effects and the main preventive measures applicable to reduce solar ultraviolet occupational risk to better protect workers.

2. MATERIALS AND METHODS

Two hundred and four (204) masons performing block laying in outdoor environment were randomly selected from different locations in Ogun State, Nigeria for investigation. The masons' thermal environments and physiology were assessed by measuring the meteorological and physiological parameters. The description of the meteorological and physiological parameters of the mason were recorded which includes the air temperature, wind speed, relative humidity, radiant temperature, solar radiation, skin and core temperatures for 12 months between January and December. The air temperature was recorded using GM013-Thermo-Hygro digital thermometer- Hygrometer with external sensor (Shenzhen Kai Heng Jie Technology Ltd, China) and the radiant temperature was recorded with infrared thermometer pointed to the blackbody. Solar radiation was measured using solar power meter SM 206 (Shenzhen Sanpo Instrument Co. Ltd, China) with resolution of 0.1 W/m^2 while the wind speed was measured using vane probe Anemometer, Am-4201 microprocessor digital anemometer (Lutron Electronics Enterprise Co. Ltd, Taiwan). The physiology of human thermo-regulation involves the measurement of body (core) temperature and skin temperature because human body responds to thermal conditions through physiological system of thermoregulation. The skin temperature was measured using infrared Smart sensor AR8720 thermometer (Shenzhen Kai Heng Jie Technology Ltd, China) number 00505613 with thermometric range of -5 ^{o}C to 1050 ^{o}C pointing to the forehead of the subject at 1.5 m to 2 m distance while Core temperature measured before every two hours using a Dx-101 water resistant digital clinical thermometer (Hicks thermometer Ltd, Indian). The data collected were analysed statistically with SPSS version 21 and Microsoft Excel (2010) software.

Figure 1: GM013-Thermo-Hygro Indoor/outdoor, Max/Min thermometer- Hygrometer with external sensor

Figure 2: Am-4201 Vane probe digital anemometer

Figure 3: SM 206 Solar power meter

Figure 4: Infrared thermometer

Figure 5: Dx-101 digital clinical thermometer

Figure 6: Mason performing block laying

Figure 7: Mason carrying block for laying

3. RESULTS AND DISCUSSION

Meteorological conditions were recorded around the subject. The mean values of meteorological conditions outdoors are presented in Table 1. Table 2 shows the mean values of physiological responses of the subjects in the outdoors environment. Table 3 shows the summary of the measured and recorded parameters.

Table 1: Mean values of the meteorological responses

Parameter		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Air temp (oC)		34.2	35.0	36.1	34.4	31.6	33.3	27.9	30.5	33.1	32.8	36.1	32.8
	SD	3.24	2.0	2.6	2.2	2.3	2.3	1.39	2.1	3.4	4.81	3.5	3.7
Relative humidity (%)		57	42	54	48	58	58	69	56	55	56	58	53
	SD	5.4	6.6	5.5	5.8	6.3	5.6	3.23	4.2	6.0	5.67	5.5	5.3
Wind speed (m/s)		0.5	0.5	0.5	0.5	0.5	0.4	0.5	0.4	0.5	0.5	0.5	0.5
	SD	0.1	0.1	9.1	0.1	0.2	0.2	0.1	0.2	0.2	0.15	0.2	0.1
Solar radiation (W/m^2)		648	484	706	660	571	583	551	779	668	771	725	806
	SD	191.2	105.5	185.5	211.5	160.9	82.2	105.2	240.9	166.6	167.9	223.8	220.8
Radiant temp (°C)		35.6	35.6	35.8	35.6	34.5	36.9	29.5	31.6	33.9	32.5	33.4	32.9
	SD	5.0	5.0	5.6	5.0	4.7	3.4	3.1	3.1	4.2	3.4	4.0	3.40

Table 2: Mean values of the physiological responses

Parameter		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Skin temp (°C)		34.3	34.5	34.8	34.6	33.1	33.2	34.4	33.5	34.0	33.9	33.9	34.1
	SD	0.2	0.9	0.30	0.17	0.6	0.5	0.48	0.7	0.47	0.52	0.52	0.5
Core temp. (°C)		36.5	36.2	36.5	36.7	36.3	36.3	36.3	36.3	36.6	36.3	36.4	36.5
	SD	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1

Table 3: Summary of the results throughout the year

Activities	Months	Minimum	Maximum	Mean	Std. Deviation
Air temp. (°C)	12	27.90	36.05	33.13	2.34
Relative humidity (%)	12	42.10	69.00	55.32	6.40
Wind speed (m/s)	12	0.42	0.53	0.48	0.03
Solar radiation (W/m^2)	12	484.90	806.20	662.73	100.31
Radiant temp. (°C)	12	29.48	36.91	34.00	2.13
Skin temp. (°C)	12	33.12	34.76	34.02	0.54
Core temp. (°C)	12	36.20	36.70	36.39	0.14

The human physiological responses were observed from 204 participants in various environmental conditions over 12 months. It is very difficult to determine the constant relationship between the human responses and outdoor climate. Similarly, the heat supplied by thermal energy to the body is equivalent to the output work of the mason performing physical activities in an environment (Musa 2016). The weather conditions of Ogun State, Nigeria was mild from January to December Table 1 shows that the lowest mean air temperature, 27.9±1.39 °C recorded in July while the highest mean air temperature, 36.1±3.54 °C occurred in November and March. Though, it was a mild weather condition over a year, but a person may be able to get cold stress or heat stress. In July, it is possible for any mason to get cold stress due to the type of cloth worn. The result showed that highest average relative humidity of 69±3.23% occurred with the lowest, 42±6.61% in February. At high humidity levels, skin moisture tends to increase discomfort, particularly skin moisture that is physiological in origin (water diffusion and perspiration) (Berglund, 1995). As a matter of fact, relative humidity affects the evaporation from the skin, which is the prevailing way of heat loss at high air temperatures, normally from 26 °C. Moreso, at lower relative humidity, more sweat is allowed to evaporate from the body, while at higher values it is harder for this process to happen, because the air's moisture content is already elevated (La Roche, 2011). Wolkoff and Kjaergaard (2007) stated that very humid environments (relative humidity > 70-80%) are usually uncomfortable because the air is close to the saturation level, thus strongly reducing the possibility of heat loss through evaporation. On the other hand, very dry environments (relative humidity < 20-30%) are also uncomfortable because of their effect on the mucous membranes (Wolkoff and Kjaergaard, 2007). Tanabe et al. (2002) reported that at high humidity levels, thermal sensation alone is not a reliable predictor of thermal comfort. The discomfort appears to be due to the feeling of the moisture itself, increased friction between skin and clothing with skin moisture (Gwosdow et al., 1986). To prevent warm discomfort, ASHRAE (2001) recommended that on the warm side of the comfort zone, the relative humidity should not exceed 60%.

Furthermore, wind speed seems to have a tendency around a year which cut across the season. This section discusses the wide-area hourly average wind vector (speed and direction) at 10 meters above the ground surface. The wind experienced at any given location is highly dependent on local topography and other factors and instantaneous wind speed and direction vary more widely than hourly average. The average hourly wind speed in Ogun state experiences significant seasonal variation over the course of the year. Table 1 also showed the fluctuation between the highest mean wind speed 0.5±0.16 m/sec and the lowest 0.4±0.16 m/sec in each month was very minimal and it may be considered that particular tendencies exist. The calmest month or the year is June and august with average hourly wind speed of 0.4±0.16 m/sec and the rest of the windiest month of the year with average hourly wind speed of 0.5±0.16 m/sec. The average mean wind speed throughout the research year was between 0.4 m/s and 0.5 m/s. The draft sensation can reduce the thermal sensation, but sensation can cause discomfort. The increase in wind speed can offset the impact of elevated ambient temperature which is also of great significance for the regulation of air conditioning system in summer (Hou, 2018).

Similarly, Table 1 also revealed that mean solar radiation was higher, 779±240.87 W/m^2 in August while the lowest radiation occurred in February with 484±105.51 W/m^2. Fluctuation of solar radiation occurred in the year due to the revolution and the change of altitude of the sun. However, the lower solar radiations in the different months seem to be influenced by cloud cover rather than the altitude (Antoniadis et al., 2020). The quality and quantity of solar radiation that reaches the surface earth varies with the elevation angle of the sun above the horizon, so the exposure may change depending from the time of the day, the day of the year and geographical location (Antoniadis et al., 2020). Air pollution may also have effect on the solar radiation reaching the ground. The mean radiant temperature was also at maximum at 36.9±3.37 oC in June while 29.5±3.10 oC was recorded as the minimum mean radiant temperature in July. This was also seemly affected by the change in the altitude. The fluctuation of the radiant temperature occurred throughout the year due to the change of the altitude of the sun (Antoniadis et al., 2020). However, the core temperature and sweat loss seemed to have been strongly affected by air temperature. Hence, the mean skin temperature is highly influenced by mean radiant temperature.

Table 2 shows that the highest mean skin temperature for the mason, 34.5±0.86 oC occurred in February while the lowest of 33.1±0.58 ^{o}C occurred in the month of May. The mean value of the skin temperature throughout the season was 34.02±0.54 ^{o}C which was in line with ASHRAE standard (ASHRAE, 2001). If the skin temperature is greater than 45 ºC or less than 18 ºC it causes pain (ASHRAE, 2001). Skin temperatures associated with comfort at sedentary activities are 33 to 34 °C and decreases with increasing activity (ASHRAE, 2001)

The human skin can absorb radiation and the skin temperature cannot be a major index for thermal comfort under large heat exchange by radiation (Musa et al., 2015). Hence, the skin temperature was not connected with the thermal conditions of the individual. The core temperature showed the highest value of 36.7 (±0.05) ºC in April with the lowest value of 36.2 (±0.05) ºC in February. In contrast to skin temperature, core temperatures rise with activity. The temperature regulatory center in the brain is about 36.8 °C at rest in comfort and increases to about 37.4°C when walking and 37.9°C when jogging (ASHRAE, 2001). The mean value of the core temperature throughout the year was 36.4±0.14 ºC and this was also a normal internal temperature for a healthy individual.

The results showed that majority of the mason were healthy during their activities. An internal temperature less than about 28 °C can lead to serious cardiac arrhythmia and death, and a temperature greater than 46 °C can cause irreversible brain damage (ASHRAE, 2001). Hence, careful regulation of body temperature is critical to comfort and health of workers in outdoor environment. However, human responses seem to be influenced by actual outdoor climate condition which consist of solar radiation and wind speed and people could have different responses due to various internal body temperature or various skin temperature. Human tend to be fuzzy in their decision space and their perception of environment depends on physiological and psychological properties which might be biased by personal, cultural and ecological expectation (Musa, 2016).

Technical implementation that satisfies everyone is therefore impossible, although, it is manageable to adapt a system to the individual. The prevention of skin and eye adverse health effects in outdoor workers exposed to solar UV needs to be based on various preventive actions, including collective technical and organizational interventions, information and specific training of workers, use of individual protective equipment, change in individual behaviors, and adequate health surveillance of exposed workers (Agarwal, 2017). However, these preventive measures are currently inadequately applied and the major reason for this would be the lack of standards, legislation, and recommendations for the prevention of this occupational risk.

4. CONCLUSION

The study concluded that the thermal discomfort has been known to lead to sick building syndrome symptoms and could affect the performance of the work output by the mason. The combination of high temperature and high relative humidity serves to reduce thermal comfort and outdoor air quality. Human responses to the thermal environment are inherently difficult to predict due to subjective assessment of outdoor users. Outdoor condition is non-steady state and it is generally accepted that human responses can be considered as the responses under transient condition. Mason should be tested and evaluated for their fitness for block laying task, and their working duration should also be optimized without discomfort to maximum efficiency of the worker for the designated task which will increase the net output.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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