RBSO
Revista Brasileira de Saúde Ocupacional
ISSN: 2317-6369 (online)

Essay
Dossier RBSO 50 Years

Daniel Pires Bitencourt[a]
https://orcid.org/0000-0001-6727-4290

Paulo Alves Maia[b]
https://orcid.org/0000-0002-6089-892X

Álvaro Cézar Ruas[b]
https://orcid.org/0000-0001-9320-902X

Irlon de Ângelo da Cunha[c]
https://orcid.org/0009-0000-6954-8750

[a]Fundação Jorge Duprat Figueiredo de Segurança e Medicina no Trabalho, Escritório Avançado no Estado de Santa Catarina. Florianópolis, SC, Brazil.
[b]Fundação Jorge Duprat Figueiredo de Segurança e Medicina no Trabalho, Escritório Avançado de Campinas. Campinas, SP, Brazil.
[c]Fundação Jorge Duprat Figueiredo de Segurança e Medicina no Trabalho, Centro Técnico Nacional. São Paulo, SP, Brazil.

Contact:
Daniel Pires Bitencourt

Email:
daniel.bitencourt@fundacentro.gov.br

How to cite (Vancouver):
Bitencourt DP, Maia PA, Ruas AC, Cunha IA. Outdoor Work: Past, Present, and Future on Occupational Heat Exposure. Rev bras saúde ocup [Internet]. 2023;48:edcinq13. Available from: https://doi.org/10.1590/2317-6369/36022en2023v48edcinq13

CC BY

Outdoor work: past, present, and future on occupational heat exposure

Trabalho a céu aberto: passado, presente e futuro sobre exposição ocupacional ao calor

Abstract

Given the current climate change and high-temperature impact on human health, especially due to global warming, actions for heat prevention focused on outdoor workers are relevant. This essay presents the results of recent research and highlights technological innovations for heat monitoring in Brazil. Also, it reflects on the future of outdoor work given climate change. Outdoor work is generally characterized as heavy, leading to higher metabolic heat production. However, Occupational Safety and Health have made few efforts to find alternatives to minimize or eliminate heat impact on workers. Moreover, the worker's protection alternatives are reduced. WBGT Monitor is presented as a technological innovation for remote heat monitoring in outdoor environments. Despite the control measures provided to workers subjected to heat, global warming demands innovative interventions and special exposure controls at outdoor workplaces. Thus, an increased commitment to knowledge production to elaborate or improve public policy is desirable.

Keywords: global warming; outdoor work; occupational health; heat stress.

Resumo

Considerando as mudanças climáticas e o impacto das temperaturas elevadas na saúde humana, especialmente devido ao aquecimento global, são relevantes as ações de prevenção ao calor voltadas aos trabalhadores que laboram a céu aberto. Neste ensaio, são apresentados resultados de recentes pesquisas, bem como destacadas inovações tecnológicas para monitoramento do calor no Brasil. Também são expostas reflexões sobre o futuro do trabalho a céu aberto diante das mudanças climáticas. O trabalho a céu aberto é em geral caracterizado por atividades pesadas, que geram elevado calor metabólico. Contudo, são escassos os esforços no campo da Saúde e Segurança do Trabalho para a busca de alternativas que minimizem ou eliminem os efeitos do calor para os trabalhadores. Além disso, as alternativas de proteção dos trabalhadores são reduzidas. O Monitor IBUTG é apresentado como inovação tecnológica de monitoramento remoto do calor em ambiente a céu aberto. Apesar das medidas de controle previstas em lei para proteção dos trabalhadores submetidos ao calor, em razão do aquecimento global, serão necessários intervenções inovadoras e controles especiais da exposição ao calor nos ambientes externos. Portanto, é desejável maior empenho na produção de conhecimento com vistas a fomentar a elaboração ou o aprimoramento de políticas públicas.

Palavras-chave: aquecimento global; ambiente externo de trabalho; estresse térmico; saúde do trabalhador.

Introduction

Outdoor work is often characterized by activities that increase workers' metabolic heat. This process is directly influenced by air temperature and other environmental parameters such as humidity, wind speed, and solar radiation, which can lead to heat stress. Workers develop heat stress as a result of the heat load to which they are exposed, which involves a combination of workplace conditions, physical activity, and their working clothes. As a consequence of heat stress, workers experience physiological stress.

The impacts of heat are extensively discussed in scientific literature, particularly in the field of Public Health[1-4]. Although studies on this topic use distinct methodologies, they generally consider "heat" to be when the air temperature in a specific region and season exceeds the average by one standard deviation or exceeds the 90th percentile. These statistical parameters should preferably be calculated from a historical data series of at least 30 years. In general, studies have shown that heat exposure leads to an increased mortality rate and to hospitalizations due to respiratory and cardiovascular diseases[1-4].

Situations in which heat persists over a wide area for at least three consecutive days are referred to as heatwaves. These heatwaves have occurred more frequently and with greater intensity in Brazil[5,6] since the 2000s. Heat exposure can lead to hospitalization for electrolyte disturbances, kidney failure, urinary tract infections, septicemia, and even heatstroke. In addition to heatstroke and rhabdomyolysis[7], which can be fatal, the most common adverse effects of heat on health include heat exhaustion, cramps, and skin problems.

It is essential for organizations to recognize the danger of occupational heat exposure as a significant risk and provide better working conditions for employees[8]. Sugarcane cutters in São Paulo, for instance, are strongly affected by heat, with occurrences of death while working[9]. These workers suffer muscular damage, which increases the risk of kidney injury[10]. The legal heat exposure limit set for these workers is exceeded during approximately 7% of their workday while they carry out heavy activity[11] and 3% while they perform moderate activity. A study focused on rural areas in northeastern Brazil showed that, if organizations followed the work/rest schedule stipulated by the previous Brazilian legislation, workers would have to stop performing heavy activity for approximately 54% of the time while moderate and light activities would have to be interrupted for about 33.5% and 6.6% of the time, respectively[12]. The classification of activity as light, moderate or heavy was used in Brazilian legislation until the end of 2019 to estimate the metabolic heat produced by workers.

Studies conducted in other countries, often focusing on climate change, have assessed workers' perception of heat[13], related occupational health to economic losses[14], evaluated social impacts and workers' adaptation strategies[15], and associated occupational health with decreased productivity at work[16]. There are also studies indicating that heat exposure increases the incidence of workplace accidents and reduces workers' productivity[17,18]. This happens due to employees reducing their work pace; taking more breaks to drink water, rest, and cool their bodies; and work absence due to heat-related illnesses[16].

Global warming is characterized by an increase in the world's average temperature and is caused by excessive global emissions of greenhouse gases such as carbon dioxide. This increase in temperature has also been observed in Brazil over the past few decades becoming more intense since the 2000s[5,6]. Projections for the future, made with long-term climate simulation models, indicate a continuing upward temperature trend[19], even under more optimistic scenarios. One of the consequences of this situation will be the increase in the frequency and intensity of heatwaves[5,6].

In this regard, global warming is an important aspect to consider in the context of occupational heat exposure. Studies on the risk of heat stress in the workplace, from the perspective of climate change, show that heat prevention measures should be focused on workers, including their training and the implementation of adaptation processes[20,21]. Another study on occupational heat exposure in the Australian construction industry pointed out the need for greater awareness of the impacts of climate change, as well as the application of practical solutions and changes to the legislation[22].

Given the context presented, this essay aims to present recent research on heat exposure, to introduce a technological innovation for heat monitoring in Brazil, and to reflect on the future of outdoor work in the face

of climate change. The study is presented in five sections, in addition to this introduction. The second section discusses recent research on the topic of heat in Brazil. The third section introduces a new technology for remote heat monitoring in outdoor environments—the WBGT Monitor. The fourth section discusses emerging themes with the potential to eliminate or minimize the effects of heat on workers. The fifth section provides a reflection on the future of outdoor work, addressing, among other aspects, future climate change scenarios. Lastly, the study presents its concluding remarks.

Research on occupational heat exposure in Brazil

Some initiatives dealing with heat exposure are focused on studies that address occupational heat exposure in outdoor environments, from a Public Health perspective. Their results clearly indicate rising temperatures in Brazil[5,23,6]. However, temperature projections obtained from numerical atmospheric simulations are even more concerning, as they suggest a future with progressively hotter days and nights[24].

Recent articles in the field of Public Health showed an increase in mortality rates due to heat in the cities of São Paulo[3] and Rio de Janeiro[4]. In activities involving occupational heat exposure, the association of key atmospheric variables with heat stress and data on deaths of sugarcane cutters has indicated the occurrence of sudden deaths. Often, these deaths occurred at the workplace, with heat being a significant contributing factor[9]. A review of over 50 articles addressing sugarcane cutters revealed that these workers are exposed to various occupational risks, with heat exposure being one of the primary ones[25].

An essential measure to protect outdoor workers exposed to heat is individual monitoring of their core body temperature. This measurement can identify the direct impacts of heat on workers' bodies by assessing various factors, including individual susceptibility, age, gender, body mass index, physical fitness, clothing, medical conditions, and the use of alcohol and drugs. The relationship between heart rate and core body temperature in heat-exposed workers has formed the basis for the proposal to the use of heart rate monitors. By analyzing warning signals, it is possible to alert workers on the need to reduce physical exertion or take breaks for recovery[26]. Technologies aimed at monitoring core body temperatures can be extremely useful for workers in strenuous labor, such as sugarcane cutters, when they are exposed to serious risks due to heavy physical activity.

Regarding environmental conditions, some studies have been conducted to diagnose the spatial and temporal variability of heat exposure in outdoor work. Numerical simulations of the Wet Bulb Globe Temperature (WBGT) index for heatwave situations have shown that, in many cases, WBGT values exceed the exposure limit during most or all of the daytime work shift[27]. WBGT estimates for sugarcane cutting work environments indicated situations in which tolerance limits were exceeded throughout the entire work shift for workers performing both heavy and moderate activities[11]. Similar estimates conducted across the country have shown an increase in the risk of heat stress in recent decades[28]. WBGT assessments projecting future temperatures in Brazil in general[19] and in its semi-arid region[29] revealed concerning outlooks regarding heat stress due to climate change. When considering only future scenarios with high greenhouse gas emissions, heat stress conditions are shown to worsen by the end of this century[30]. However, subsequent studies have concluded that the future heat stress situation in Brazil will be worse in both the pessimistic and optimistic scenarios regarding greenhouse gas emissions[19].

WBGT remote monitoring in Brazil

The Wet Bulb Globe Temperature (WBGT) index, adopted by the International Organization for Standardization (ISO 7243)[31], is used to assess occupational heat exposure in many countries around the world. In Brazil, Annex 3 of Regulatory Standard 15 (NR 15)[32], which deals with hazardous activities and operations, stipulates that heat exposure should be analyzed using the WBGT index. The Occupational Hygiene Standard 06 (NHO 06)[33] details the standard procedures for assembling and using equipment/instruments to measure the necessary temperatures for calculating this index: the dry bulb temperature, the natural wet bulb temperature, and the globe temperature.

Daily monitoring of the WBGT in outdoor workplaces is operationally difficult and often unfeasible due to the need for specialized equipment and human resources. To address these challenges and enable statistical applications using historical data series, some studies have proposed estimating WBGT using atmospheric data. Such data are automatically measured by meteorological stations using a standard defined by the World Meteorological Organization (WMO), allowing for an adequate spatial representation of all atmospheric variables. However, since the natural wet bulb and globe temperatures—which are necessary for WBGT calculation—are not part of the data provided by meteorological stations, it is necessary to estimate these two temperatures based on other atmospheric variables related to heat stress.

Thus, in 2009, the Jorge Duprat Figueiredo Foundation for Safety and Occupational Medicine (Fundacentro) conducted field measurements of the Wet Bulb Globe Temperature (WBGT) and statistically related these measurements to atmospheric data in order to develop a WGBT estimation methodology suitable for the Brazilian climate. The proposal, presented by Maia et al.[34], estimates the natural wet bulb temperature using a multiple regression equation and the globe temperature using the globe thermal balance equation. These temperatures, along with the dry bulb temperature, measured by meteorological stations, allow for the final calculation of WBGT. This method represents a historical milestone for remote WBGT monitoring in Brazil, as it enabled numerous research studies and significant technological innovations, such as the development of the WBGT Monitor.

The WBGT Monitor tool originated from the Thermal Overload software, developed by Fundacentro in the mid-2010s, which uses in its calculation base the WBGT estimation method by Maia et al[34]. The WBGT Monitor—currently available online (https://monitoributg.fundacentro.gov.br/Inicio) and as a smartphone application (Android and iOS)—serves preventive purposes with the advantage of eliminating the need to travel to the workplace along with all other operational difficulties in monitoring outdoor heat exposure. The availability of this tool in the form of a smartphone application has expanded the reach of information, especially for rural workers, the intended target of this technological innovation.

The WBGT Monitor uses atmospheric data collected in all Brazilian regions via the network of meteorological stations of the National Institute of Meteorology (Inmet). Thus, WBGT monitoring and a comprehensive assessment of occupational heat exposure are presented in near real-time, daily, and every hour during the daytime work shift. Furthermore, these results can be obtained for the entire historical data series available from Inmet, enabling statistical assessments of past periods for technical reports and scientific studies. In its latest update, the WBGT Monitor began to estimate the WBGT using data from the ETA Atmospheric Simulation Model provided by the National Institute for Space Research (Inpe). With this new database, the user can plan daytime work shifts for the current day and the seven subsequent days, as well as obtain recommendations for preventive and control measures available in the system.

Emerging topics

There is still much to investigate and develop to effectively prevent and control occupational heat exposure. Individual and continuous monitoring, with estimates or direct measurements, of a worker's core body temperature is an important area of focus to prevent heat-related harm.

The individual monitoring of heat exposure can allow for issuing alerts when reversible heat stress occurs. Since this process is primarily influenced by the worker's activity type and by the heat conditions in the workplace (thermal overload), individual heat stress alerts can help prevent risky situations, thereby promoting the prevention of disease and death. The prospects for this type of solution tend to increase with recent technological advancements, such as the deployment of 5G mobile internet technology in Brazil, which has opened up opportunities for communication and monitoring, especially in terms of risk situation alerts, even in rural environments.

Investigations on outdoor work productivity are also important, given the many Brazilian regions with high temperatures. Fatigue can impair the physical and mental capacity of construction workers[35]. Occupational heat exposure directly affects health and productivity, requiring actions to mitigate the effects of climate change[36]. Furthermore, studies on acclimatization are highly relevant since many workers in Brazil migrate from relatively

cooler regions to warmer areas. Lastly, considering that metabolic heat is a key aspect in evaluating occupational heat exposure, studies aimed at improving the estimation of a worker's metabolic rates during different types of work activities are of paramount importance.

Other important topics for control and prevention are related to the development of clothing suitable for heat exposure[37], with more effective thermal insulation fabrics, and the introduction of new technologies for the production of personal protective equipment (PPE) designed for this purpose.

Reflections on the future of outdoor work

The thesis of rising temperatures due to climate change has been widely accepted by the scientific community and governments, leading to significant efforts to find alternatives that minimize or eliminate the effects of heat on the productive sector and the economy. However, in general, the same level of commitment is lacking in the field of Occupational Health and Safety, especially concerning those who work outdoors. Outdoor work is often characterized by heavy activities that cause high metabolic heat. Furthermore, worker protection alternatives are limited and involve the complex operationalization of preventive measures. Currently, these measures are primarily limited to wearing light and loose clothing, using sunscreen, reducing exposure time through rotations, taking breaks, and encouraging hydration and salt intake. Therefore, strategic planning for outdoor work activities in the short and medium term is a priority, especially if it focuses on incentives for research, technological innovation, and adjustments to labor legislation.

In the future, other technological innovations are expected, such as the development of clothing that can acts as a thermal barrier, with greater efficiency in transferring body heat to the environment. Considered one of the main possibilities, garments with phase change materials (PCM) [37] and cooling vests[38] have good potential to prevent physiological stress caused by heat stress in outdoor work. Another possibility is the development of a human exoskeleton, a structure powered by an electric motor system, providing body parts with more movement, strength, and endurance. This type of assistance could reduce workers' fatigue and enhances their ability of lifting loads and transporting materials, resulting in less metabolic heat generation. Equally important is the development or improvement of existing thermal overload monitoring systems, both for workers[26] and workplaces[34].

In practice, however, the application of these technologies is likely to be feasible only in a favorable socio-economic scenario, as technology development often depends on government incentives. Furthermore, guiding public policies is necessary to benefit workers exposed to unhealthy conditions, with constant updates of regulatory standards ensuring the adoption of effective preventive procedures in the workplace. The proper implementation of these standards depends on a broad and complex spectrum, including enforcement, political forces, the representation of various worker categories, company characteristics, work organization, geographic location, economic and technical resources, among others.

On the other hand, it is essential to question whether technological innovations will occur to improve outdoor work, eliminating hazardous and unhealthy conditions, or if they will be toward the complete mechanization of work, seeking greater productivity. Some studies conclude that economic interests often take precedence over worker health concerns[39]. In rural work, for example, the execution and continuity of manual activities will depend heavily on public policies that allow workers to preserve their integrity and health. If future choice favors human labor, investments should prioritize the preservation of workers' safety and health. Notably, even in more optimistic climate scenarios, with lower greenhouse gas emissions, Brazil will still have areas under critical heat stress, rendering any type of outdoor work unfeasible[19].

Finally, we believe that, even with the means to identify risky situations and access protective measures, policies will be required to induce their adoption. Given this context and the prospects of worsening heat conditions due to climate change, it is essential for everyone involved in the work process to be aware of the risks associated with heat[20]. In Brazil, analyses of the current situation show that the break regime, specified in NR 15[32] as one of the fundamental measures to prevent thermal overload, is rarely respected by employers. The piece-rate pay system is another extremely critical situation that further exacerbates the problem since it drives workers to exceed

their physical limits in order to obtain what is necessary for survival[39]. To change the condition of outdoor work, will require efforts from government labor and health agencies and worker representations to induce employers to follow appropriate protective measures.

Conclusions

Without diminishing the importance of numerous initiatives presented for controlling heat exposure, the NHO 06[33] and the methodology by Maia et al.[34] have stood out. The NHO 06[33] is considered a technical reference, especially concerning procedures and heat assessment methods. The proposal by Maia et al.[34] has facilitated the comprehensive evaluation of occupational heat exposure in all outdoor areas of Brazil, with the use of the WBGT Monitor. This method enables the development of scientific studies, including historical heat risk analyses using meteorological data[11,28]. Furthermore, important insights for medium- and long-term strategic planning can be obtained by estimating future WBGT values through numerically simulated meteorological data collected from climate change models[19].

Since the early 2000s, the impacts of climate change in Brazil have been observed, particularly with the increased frequency and intensity of heatwaves. While the application of protective technologies may still be a distant scenario, addressing the issues related to workers' health, well-being and lives is urgent. In this sense, it is of utmost importance to pay attention to these workers, including employing the mechanisms already provided for in Annex 3 of NR 09[40].

In the future, outdoor work in Brazil is believed to become even more challenging due to rising temperatures, requiring concentrated efforts in research, technological innovation, and public policies.

References

1. Son JY, Gouveia N, Bravo MA, Freitas CU, Bell ML. The impact of temperature on mortality in a subtropical city: effects of cold, heat, and heat waves in São Paulo, Brazil. Int J Biometeorol. 2016;60(1):113-21.
2. Orru H, Åström DO. Increases in external cause mortality due to high and low temperatures: evidence from northeastern Europe. Int J Biometeorol. 2017;61(5):963-6.
3. Ikefuti PV, Barrozo LV, Braga AL. Mean air temperature as a risk factor for stroke mortality in São Paulo, Brazil. Int J Biometeorol. 2018;62(8):1535-42.
4. Geirinhas JL, Trigo RM, Libonati R, Castro LCO, Sousa PM, Coelho CAS, et al. Characterizing the atmospheric conditions during the 2010 heatwave in Rio de Janeiro marked by excessive mortality rates. Sci Total Environ. 2019;650(1):796-808.
5. Bitencourt DP, Fuentes MV, Maia PA, Amorim FT. Frequência, duração, abrangência espacial e intensidade das ondas de calor no Brasil. Rev Bras Meteorol. 2016;31(4):506-17.
6. Bitencourt DP, Fuentes MV, Franke AE, Silveira RB, Alves MP. The climatology of cold and heat waves in Brazil from 1961 to 2016. Int J Climatol. 2020;40(4):2464-78.
7. Xiang J, Bi P, Pisaniello D, Hansen A. The impact of heat waves on workers' health and safety in Adelaide, South Australia. Environ Res. 2014;133:90-5.
8. Rosa VC, Lima LEM. O estresse térmico visto como um risco ocupacional. R Gestão Industrial. 2019;15(2):53-73.
9. Bitencourt DP, Ruas AC, Maia PA. Análise da contribuição das variáveis meteorológicas no estresse térmico associada a morte de cortadores de cana-de-açúcar. Cad Saude Publica. 2012;28:65-74.
10. Diniz CO, McKenna Z, Canuto LBS, Magalhães F, Machado-Moreira CA, Shibuya E, et al. A preliminary evaluation of the kidney function of sugarcane cutters from Brazil. J Occup Environ Med. 2021;63(2):e53-8.
11. Roscani RC, Bitencourt DP, Maia PA, Ruas AC. Risco de exposição à sobrecarga térmica para trabalhadores da cultura de cana-de-açúcar no estado de São Paulo, Brasil. Cad Saude Publica. 2017;33(3):e00211415.
12. Roscani RC, Maia PA, Monteiro MI. Sobrecarga térmica em áreas rurais: a influência da intensidade do trabalho. Rev Bras Saude Ocup. 2019;44:e14.

13. Xiang J, Hansen A, Pisaniello D, Bi P. Workers' perceptions of climate change related extreme heat exposure in South Australia: a cross-sectional survey. BMC Public Health. 2016;16:549.

14. Kjellstrom T. Impact of climate conditions on occupational health and related economic losses: a new feature of global and urban health in the context of climate change. Asia Pac J Public Health. 2016;28(2 Suppl):28S-37.

15. Nunfam VF, Adusei-Asante K, Van Etten EJ, Oosthuizen J, Frimpong K. Social impacts of occupational heat stress and adaptation strategies of workers: a narrative synthesis of the literature. Sci Total Environ. 2018;643:1542-52.

16. Levi M, Kjellstrom T, Baldasseroni A. Impact of climate change on occupational health and productivity: A systematic literature review focusing on workplace heat. Med Lav. 2018;109(3):163-79.

17. Calkins MM, Bonauto D, Hajat A, Lieblich M, Seixas N, Sheppard L, et al. A case-crossover study of heat exposure and injury risk among outdoor construction workers in Washington State. Scand J Work Environ Health. 2019;45(6):588-99.

18. Fatima SH, Rothmore P, Giles LC, Varghese BM, Bi P. Extreme heat and occupational injuries in different climate zones: A systematic review and meta-analysis of epidemiological evidence. Environ Int. 2021;148:106384.

19. Bitencourt DP, Alves LL, Shibuya EK, Cunha I, Souza JP. Climate change impacts on heat stress in Brazil-past, present, and future implications for occupational heat exposure. Int J Climatology. 2020;41:2741-56.

20. Nunfam VF, Oosthuizen J, Adusei-Asante K, Etten EJV, Frimpong K. Perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana. Sci Total Environ. 2019;657:365-78.

21. Nunfam VF, Etten EJV, Oosthuizen J, Adusei-Asante K, Frimpong K. Climate change and occupational heat stress risks and adaptation strategies of mining workers: perspectives of supervisors and other stakeholders in Ghana. Environ Research. 2019.169:147-55.

22. Hurlimann AC, Warren-Myers G, Browne GR. Is the Australian construction industry prepared for climate change? Building Environ. 2019;153:128-37.

23. Geirinhas JL, Trigo RM, Libonati R, Coelho CA, Palmeira AC. Climatic and synoptic characterization of heat waves in Brazil. Int J Climatology. 2017;38:1760-76.

24. Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, et al., editors. Climate Change 2013: the physical science basis: contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press; 2013. p. 1535.

25. Leite MR, Zanetta DMT, Trevisan IB, Burdmann EA, Santos UP. Sugarcane cutting work, risks, and health effects: a literature review. Rev Saude Publica. 2018;52:80.

26. Ruas AC, Maia PA, Roscani RC, Bitencourt DP, Amorim FT. Heat stress monitoring based on heart rate measurements. Rev Bras Med Trab. 2020;18:232-40.

27. Bitencourt DP. Maximum wet-bulb globe temperature mapping in Central-South Brazil: a numerical study. Meteorol Applic. 2019;26(3):385-95.

28. Bitencourt DP, Maia PA, Roscani RC. The heat exposure risk to outdoor workers in Brazil. Arch Environ Occup Health. 2019;74:1-8.

29. Oliveira BFA, Silveira IH, Feitosa RC, Horta MAP, Junger WL, Hacon S. Human heat stress risk prediction in the Brazilian semiarid region based on the Wet-Bulb Globe temperature. Anais Acad Bras Cienc. 2019;91:e20180748.

30. Nobre CA, Marengo JA, Soares WR. Climate change risks in Brazil. Cham: Springer; 2019.

31. ISO 7243:2017. Ergonomics of the Thermal Environment - Assessment of Heat Stress Using the WBGT (Wet Bulb Globe Temperature) Index [Internet]. [place unknown]: ISO; 2017 [cited Oct 23, 2023]. Available from: https://www.iso.org/obp/ui/en/#iso:std:iso:7243:ed-3:v1:en.

32. Brasil. Ministério do Trabalho e Previdência. NR-15 – Atividades e Operações Insalubres. Brasília (DF): Ministério do Trabalho e Previdência; 2022.

33. Giampaoli E, Saad IFSD, Cunha IA, Shibuya EK. Norma de higiene ocupacional: NHO 06: procedimento técnico: avaliação da exposição ocupacional ao calor. São Paulo: Fundacentro; 2017.

34. Maia PA, Ruas AC, Bitencourt DP. Wet-bulb globe temperature index estimation using meteorological data from São Paulo State, Brazil. Int J Biometeorol. 2015;59:1395-403.

35. Rowlinson S, Yunyanjia A, Li B, Chuanjingju C. Management of climatic heat stress risk in construction: a review of practices, methodologies, and future research. Accid Anal Prev. 2014;66:187-98.

36. Flouris AD, Dinas PC, Ioannou LG, Nybo L, Havenith G, Kenny GP, Kjellstrom T. Workers' health and productivity under occupational heat strain: A systematic review and meta-analysis. Lancet Planet Health. 2018;2(12):e521-31.

37. Zeng S, Pian S, Su MS. Hierarchical-morphology metafabric for scalable passive daytime radiative cooling. Science. 2021;373(6555):692-6.

38. Golbabaei F, Heydari A, Moradi G, Dehghan H, Moradi A, Habibi P. The effect of cooling vests on physiological and perceptual responses: a systematic review. Int J Occup Saf Ergon. 2022;28(1):223-55.

39. Silva CP, Azevedo C, Monte A, Costa PFF. Condições de trabalho no cultivo da cana-de-açúcar no Brasil e repercussões sobre a saúde dos canavieiros. Rev Bras Saude Ocup. 2021;46:e22.

40. Brasil. Ministério do Trabalho e Previdência. NR-09 – Avaliação e controle das exposições ocupacionais a agentes físicos, químicos e biológicos. Brasília (DF): Ministério do Trabalho e Previdência; 2022.

Authors' contributions: Bitencourt DP contributed to the conception, literature review, and critical review of the article. Bitencourt DP, Maia PA, Ruas AC, Cunha IA participated in the writing of the article, reviewed its final version, and assume full responsibility for the content published.

Data availability: all the dataset supporting the results of this study can be found within the article itself.

Funding: the authors declare that this work was not funded.

Competing interests: the authors declare that there are no conflicts of interest.

Presentation at a scientific event: the authors inform that this study has not been presented at a scientific event.

Received: October 04, 2022
Revised: September 14, 2023
Accepted: September 15, 2023

Editor-in-Chief
Ada Ávila Assunção