INFLUENCE OF CLIMATE CHANGE ON WORKING CONDITIONS IN THE LATE 21ST CENTURY[1]

PLÍNIO MARCOS BERNARDO DE SOUZA[2]
MARCELO DE PAULA CORRÊA[3]
ROGER RODRIGUES TORRES[4]
LUIZ FELIPE SILVA[5]

Introduction

Human survival and livelihood has always been related to work and activities conducted outdoors. As technology advanced humans began to work less outdoors and more indoors, leaving the fields for industry and office work. The ever increasing strive towards increased productivity, in both external and internal environments, led to workers sometimes being subjected to accelerated and sometimes inhumane production process. This was followed shortly by new work-related health problems. These problems are directly related to environmental risk factors at the workplace, such as extreme temperatures and excess vibration or noise levels (CHENG et al., 2012).

Extreme temperature levels can cause great harm to outdoor workers. Other variables, such as humidity and solar radiation, can effect male fertility, or result in exhaustion, cramps, fatigue, headaches, decreased concentration, decreased productivity, a lowered working capacity, or in some cases even cause death (BATIZ et al., 2009; DJONGYANG; TCHINDA; NJOMO, 2010). Other conditions resulting from excess thermal stress are increased heart rate, increased sweating, dehydration, seizures, dizziness, and increased insolation time (WILSON; CRANDALL, 2011; BITENCOURT; RUAS; MAIA, 2012).

Given frequent accidents and illnesses caused by excess heat at metallurgical and textile factories in the early nineteenth century, researchers began to study human exposure

1. Acknowledgments: This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001; Foundation for Research of the State of Minas Gerais (Fapemig) - Project: CRA-APQ-00307-14; and National Council for Scientific and Technological Development (CNPq) - Project: 304701 / 2016-5.

2. Environmental Engineer and Master in Environment and Water Resources from the Federal University of Itajubá (Unifei). E-mail: pliniobsouza@yahoo.com.br

3. Meteorologist, Master and Doctor of Science from the University of São Paulo (USP). Associate Professor at the Federal University of Itajubá (Unifei). E-mail: mpcorrea@unifei.edu.br - ORCID: 0000-0002-4821-3828

4. Physicist, Master and PhD in Meteorology from the National Institute for Space Research (INPE). Associate Professor at the Federal University of Itajubá (Unifei). E-mail: roger.torres@unifei.edu.br - ORCID: 0000-0002-5684-3125

5. Engineer, Master and Doctorate in Public Health from the University of São Paulo (USP). Associate Professor at the Federal University of Itajubá (Unifei). E-mail: lfelipe@unifei.edu.br - ORCID: 0000-0002-3174-9984.

to adverse thermal conditions in the workplace and what it implied for human health (JUNIOR et al., 2012). Seeking to improve working conditions, some main parameters for evaluating work environments and processes related to heat exposure and its risks to human health were identified as "thermal stresses". These were defined as adverse psychophysiological conditions resulting from extreme environmental exposure, whether associated to cold or heat (LAMBERTS, 2011).

Thermal stress can be estimated using mathematical indices (PALLOTTA; HERDIES; GONÇALVES, 2015). These tools depend on environmental and physiological variables, and the simplest indices are those that consider only environmental variables, as these can be derived using weather stations (MORAN et al., 2001). The main variables are air temperature, relative humidity, solar radiation, and wind speed (DJONGYANG; TCHINDA; NJOMO, 2010; LAMBERTS, 2011). These variables are important in determining thermal sensation because they influence the mechanisms of thermal exchange between the human body and the environment (LAMBERTS, 2011). It is the equilibrium or imbalance of heat exchange that causes a sensation of comfort or discomfort that may culminate in thermal stress.

A large number of scientific studies have identified significant changes in Earth's climate in recent decades (IPCC, 2013). In Brazil, climate change has already been observed in increased temperatures, changes in precipitation patterns, and changes in extreme weather events, i.e. increased droughts, or more frequent, more intense, and longer lasting heat waves (MARENGO et al., 2010; DONAT et al., 2013; PBMC, 2014; CECCHERINI et al., 2016; SALVIANO et al. 2016; BITENCOURT et al.; 2016, GEIRINHAS et al. 2017). These adverse changes result in conditions conducive to thermal stress, causing health risks and reducing the productivity of outdoor workers (BITENCOURT; MAIA; ROSCANI, 2019; BITENCOURT, 2019).

Projections have been estimated by the scientific community based on future tendencies in greenhouse gas (GHG) emissions to estimate future climate change and to verify its possible impacts on society. Emission scenarios are used as input data in numerical climate system models in order to provide information as to future climate conditions (VAN VUUREN et al., 2011).

In the fifth and most recent report from the Intergovernmental Panel on Climate Change (IPCC) - IPCC AR5, four future scenarios for radiative forcing[6], the so-called Representative Concentration Pathways (RCPs), were established. RCPs are the measurements of influence that one or more factors have on altering the energy balance in a climate system (VAN VUUREN et al., 2011). Each RCP may result from future economic, technological, demographic, or political changes (IPCC, 2014b). According to Moss et al. (2010), the four RCPs are:

- RCP 2.6: mitigation scenario, where radiative forcing is around 3.0 Wm^{-2} and equivalent CO_2 concentration peaks at about 490 ppm before 2100 and declines thereafter. This is a scenario that seeks to keep global temperature increases below 2°C compared

6. Radiative forcing is defined as the difference in net irradiance in the tropopause, in Wm-2 units, between a disturbed state caused by a forcing agent and a reference state (PBMC, 2014).

to pre-industrial era temperatures. This is the least pessimistic scenario of all the RCPs, wherein GHG emissions increase and then decrease.

• RCP 4.5: intermediate scenario, where radiative forcing is approximately 4.5 W m^{-2} and the equivalent CO_2 concentration is around 650 ppm by 2100. This projection is consistent with stabilizing global energy demand, strong reforestation programs and strict climate policies.

• RCP 6.0: intermediate scenario, where radiative forcing is about 6.0 Wm^{-2} and the equivalent CO_2 concentration is around 650 ppm by 2100. This scenario and scenario RCP 8.5 do not include additional efforts to contain GHG emissions. They project GHG stabilization by the end of the century, not exceeding the mentioned values for radiative forcing and equivalent CO_2.

• RCP 8.5: pessimistic scenario, where radiative forcing and the equivalent CO_2 concentration in 2100 are greater than 8.0 W m^{-2} and 1,370 ppm, respectively. This scenario projects a sharp increase in CO_2 emissions during the 21st century due to continuous population growth and slow technological development. This scenario is considered quite pessimistic in terms of GHG emissions, and is consistent with lacks in climate policies directed towards reducing emissions as well as a continued heavy reliance on fossil fuels.

All the aforementioned factors contribute to thermal stress for outdoor workers, and can cause several health problems and impact worker performance. According to Kjellstrom (2000), work capacity can be defined as the percentage of effective work per each working hour. If no rest time is required, work capacity is 100% during one working hour. If a 25% rest time were required, work capacity would be 75% (KJELLSTROM; HOLMER; LEMKE, 2009). It is important to be able to estimate thermal stress because work capacity is calculated using thermal stress.

Kjellstrom, Holmer and Lemke (2009) showed that workers exposed to intense heat can suffer from thermal stress, have decreased work and mental capacity, and have an increased risk of work-related accidents. Batiz et al. (2009) mention that physiological manifestations such as headache, fatigue, sensory alteration, depression, sleep loss, memory loss and motor incoordination have frequently appeared in people affected by temperature increases. Lida (2005) shows that when humans are exposed to high temperatures, work speed, degree of concentration, and performance all decrease. Work breaks become more frequent and the frequency of errors tends to increase significantly from 30 ºC on. Sterner (2015) states that climate change will certainly cause increased absenteeism at work.

Deaths related to outdoor work have been reported at various locations around the world due to excess heat. In the USA a study identified that 423 rural worker deaths related to excessive heat occurred from 1992 to 2006 (KJELLSTROM; HOLMER; LEMKE, 2009). In France, many work-related deaths from hyperthermia were identified during the 2003 heat wave (LÉTARD; FLANDRE; LEPELTIER, 2004). In India, where people are regularly subjected to heat stress due to high temperatures and humidity, a heat wave caused 3,000 deaths in 2003 (DUNNE; STOUFFER; JOHN, 2013).

Leaman and Bordass (2001) report large differences in productivity among workers who regarded their work environment as thermally comfortable versus those who regarded it as being uncomfortable. Workers who reported an uncomfortable work environment were 8.8% less productive compared to those who reported a comfortable environment, that were 4% more productive.

A study carried out in Australia in 2013 and 2014 found that 77% of interviewed workers stayed at home or had their work performance impaired for at least one day due to high temperatures (ZANDER et al., 2015). These researchers came to the conclusion that the productivity losses for the affected Australian workforce, due to excessive heat, resulted in economic losses equivalent to $6.2 billion, on average, corresponding to 0.33 - 0.47% of the country's GDP in 2014.

Climate change should primarily impact those who work outdoors, i.e. farmers, miners, ranchers, street sweepers, postmen, electric energy transmission and distribution workers, and construction workers, among others. Climate changes will alter the magnitude of the environmental variables used to determine thermal stress, thus causing a decrease in the working capacity of these professionals. In face of such changes, workers are likely to have aggravated health effects, since protective measures like ventilation and cooling cannot yet be applied at outdoor work sites (VILELA et al., 2015).

Knowing how climate changes can influence working conditions and health conditions of outdoor workers is important on a fundamental and socioeconomic level, given the great influence of these workers in economic terms. Advances in climate studies can contribute to understanding the influence of climate change on this group of workers and provide information to implement measures that seek to mitigate or adapt to these changes.

The objective of this study is to evaluate the possible influence of climate change towards the end of the 21st century on outdoor working conditions by comparing working capacity under climate conditions from 1979 to 2005 with future climate projections for 2071 to 2100 using various Earth climate models.

Materials and methods

This study assessed the influence of climate change towards the end of the 21st century on outdoor working conditions by comparing simulated conditions from 1979 to 2005 with future climate projections for 2071 to 2100. The simulations and projections were based on the Environmental Stress Index (ESI) thermal stress index, and on data from eight Coupled Model Inter-comparison Project Phase 5 (CMIP5) climate models. These eight models were the CSIRO-Mk3.6.0, GFDL-ESM2G, GFDL-ESM2M, IPSL--CM5A-LR, IPSL-CM5A-MR, MIROC5, MIROC-ESM-CHEM and MRI-CGCM3 models. These models have different horizontal resolutions ranging from 1° to 3° latitude/longitude. For reasons of inter-comparison we interpolated these resolutions to a regular 1° x 1° latitude / longitude grid using bi-linear interpolation.

The CMIP5 climate models form the basis of climate change assessments in the IPCC AR5, published in 2014 (IPCC 2014b). This set of models contains data on the environmental variables that are required to calculate the ESI and, therefore, to estimate work capacity. Future climate projections were based on climate scenarios RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5.

The ESI was calculated using simulated historical variables from the CMIP5 to test the dexterity of the climate models. Reanalysis variables were taken from the WATCH--Forcing-Data-ERA-Interim (WFDEI) database, with a horizontal resolution of 0.5º x 0.5º latitude/longitude, and time interval of 3h, which we will consider as reference data. These data were transformed into daily averages, and bi-linearly interpolated to a 1º x 1º latitude/longitude horizontal resolution to compare the climate model data. Despite having have intrinsic errors, reanalysis data are widely used in existing literature to address the deficient spatial and temporal coverage of observed data (WEEDON et al., 2014).

Surface air temperature, relative humidity, and solar radiation were used as environmental variables to calculate ESI. These variables used for each simulation and projection were annual averages obtained from daily data of each model for both databases. These were calculated for each grid point covering South America with a 1º x 1º latitude/longitude horizontal resolution.

To estimate the work capacity it was necessary to calculate the heat stress experienced by the worker and to define each activity as either being mild, moderate or heavy.

According to Brazilian Regulatory Standard No. 15 - NR 15: Unhealthy Activities and Operations (BRAZIL, 1978), heat stress should be calculated using a Wet Bulb Globe Temperature (WBGT) meter. This index considers the dry bulb temperature, the wet bulb temperature, and the globe temperature variables in its calculation. Since these last two variables were not available in the database chosen, the Environmental Stress Index (Equation 1) was used because it has high correlation ($R^2 \geq 0.920$) with the WBGT, and can even be used to replace it (MORAN et al., 2005). Moran et al. (2001) highlight that the ESI is advantageous because it uses variables that can easily be obtained from weather stations. Brandão, Silva and Assireu (2013) say that ESI, combined with geographic information tools, can prove to be very useful to evaluate health risks to workers, especially for those who work outdoors. The ESI is calculated in Equation (1) (MORAN et al., 2001):

$$ESI = 0.63TA - 0.03UR + 0.02RS + 0.054(TA.UR) - 0.073(0,1 + RS)^{-1} \quad (1)$$

where:

- TA is the Air Temperature (ºC);
- UR is the relative humidity (%); and
- RS is the incidence of solar radiation (W m^{-2}).

The ESI was first calculated for each day of the year for the periods between 1979 to 2005, and 2071 to 2100. The results were then categorized into the five groups established by Zhao et al. (2015), absent thermal stress, mild thermal stress, moderate thermal stress, severe thermal stress, and extreme thermal stress (Table 1). This was done in order to evaluate if the thermal stress will increase, decrease or remain constant over the years.

Table 1 – The ESI thermal stress index categories used in this study

ESI Categorization				
CAT0	**CAT1**	**CAT2**	**CAT3**	**CAT4**
Absent thermal stress	Mild thermal stress	Moderate thermal stress	Severe thermal stress	Extreme thermal stress
< 28 units	28 to 32 units	32 to 35 units	35 to 40 units	> 40 units

Source: Zhao et al. (2015).

The annual average for daily data was calculated using the categorized index in order to obtain the category for each analyzed year. It was thus possible to calculate the average temporal occurrences of the thermal stress categories in the studied periods. Since data were calculated for each of the eight models, an average was taken in order to obtain data that represented all of them (SOUZA, 2017).

The type of activity performed by the worker (light, moderate or heavy) is classified according to the metabolic rates of the evaluated group of workers. Occupational Hygiene Standard No. 06 (NHO06) from the *Jorge Duprat Figueiredo - Fundacentro* Foundation (FUNDACENTRO, 2002) was used for the metabolic rates. Then, these values were compared with NR 15 to determine the type of activity of the group of workers chosen. The guidelines established by the American Conference of Governmental Industrial Hygienists (ACGIH, 2017), were also used in the analysis. The ACGIH is an internationally recognized entity in the area of industrial hygiene. These guidelines served as a technical reference for the two Brazilian standards in Industrial Hygiene.

Table 2 was used to estimate the working capacity of the chosen workers taking the thermal stress value and the type of activity performed by the group of workers.

Table 2 - Worker capacity according to the type of activity performed and the thermal stress to which the worker is exposed

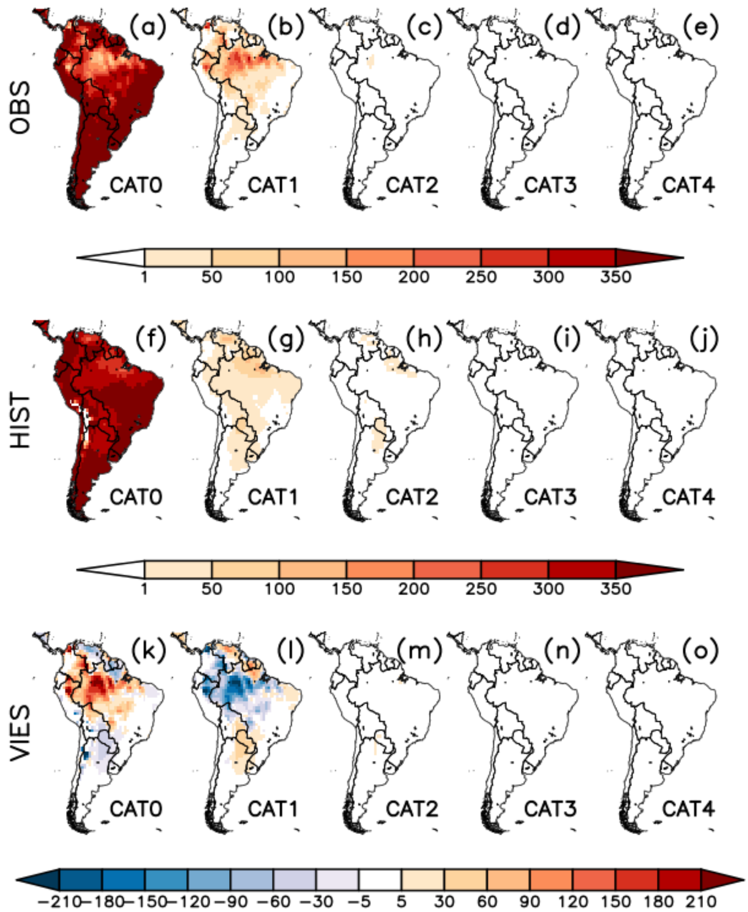
Intermittent work regime with work breaks (per hour)	Work Capacity (%)	ESI Values (units)		
		Activity		
		Light	Moderate	Heavy
Continuous work	100	Up to 30.0	Up to 26.7	Up to 25.0
45 minutes work 15 minutes rest	75	30.1 to 30.5	26.8 to 28.0	25.1 to 25.9
30 minutes work 30 minutes rest	50	30.7 to 31.4	28.1 to 29.4	26.0 to 27.9
15 minutes work 45 minutes rest	25	31.5 to 32.2	29.5 to 31.1	28.0 to 30.0
Work is not permitted without appropriate control measurements	0	Above 32.2	Above 31.1	Above 30.0

Source: Adapted from Brazilian Regulatory Standard No. 15 (BRAZIL, 1978).

Results and discussions

Figure 1 shows the ESI simulations for climate conditions between 1979 and 2005. The data refer to the average occurrence of stress categories in number of days per year for the observed and simulated data, as well as the associated bias (simulation minus observation) when comparing the two data sources.

Figure 1 - Annual average occurrence (number of days per year) of the five ESI categories for observed (OBS) and simulated (HIST) data and associated bias (HIST--OBS), both from 1979 to 2005

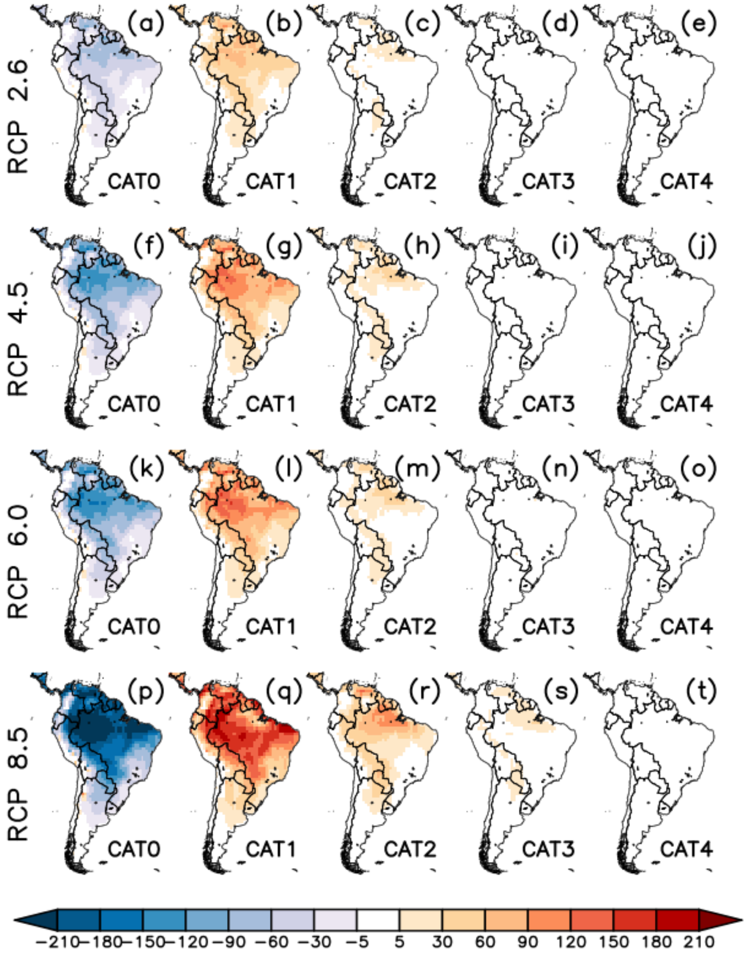


Source: Elaborated by the authors

CAT0 and CAT1, which respectively indicate the absence of thermal stress, and low levels of thermal stress, occur more frequently for climate conditions between 1979 and 2005. In comparison with observed data, the models were correct when simulating the thermal stress in regions where biases are low. This study considered values between -30 to +30 days in the year. This occurred for most of South America, mainly in the far South, Southeast, East, and the Far West (Figure 1 k-l). By contrast, there is greater bias for CAT0 and CAT1 in the Amazonian region, in Paraguay, northern Venezuela, Colombia, Peru, and Bolivia. However, the CAT0 climate model predominantly overestimates values (up to +240 days year $^{-1}$) while underestimate values in the CAT1 climate model (up to -240 days year $^{-1}$). For this reason, projections made for these regions should be evaluated with greater caution.

The ESI projections for the future climate scenarios are presented in Figure 2.

Figure 2 - Occurrence change projections (2071 - 2100), in number of days per year, of ESI categories for all RCP scenarios. The values of change were calculated with reference to the simulations (historical) in the base climatological period of 1979 - 2005.



Source: Elaborated by the authors.

According to Figure 2, future climate projections indicate increased thermal stress levels in number of days, and increased mild and moderate thermal stress levels in number of days. The higher the radiative forcing, the more frequent and broader this effect, translating to a more pessimistic scenario. Coverage is similar for CAT0 and CAT1, decreasing in CAT0, and increasing in CAT1. In CAT1 the effect extends to more than 70 days in the year for most of South America. For CAT2 (moderate heat stress), thermal stress levels increase, in number of days, in the Amazonian regions, in Paraguay, northern Venezuela, Colombia, Peru, and Bolivia. Extreme and severe heat stress conditions, CAT3 and CAT4, were virtually unchecked.

In summary, the results for both simulated and observed values for CAT0 show a predominance of comfortable thermal conditions (ESI <28 units) for years between 1979 and 2005 (Figures 1a and 1-f). However, projections for the late 21st century indicate that outdoor workers may experience mild thermal stress conditions - CAT1 ($28.0 \leq$ ESI <32.0 units), and moderate thermal stress conditions - CAT2 ($32.0 \leq$ ESI <35.0 units) in most of the South American continent.

Impact on outdoor working capacity was then estimated for both periods using the results of these simulations and projections. CAT1 was considered for this analysis since CAT2 had lower occurrence and was present in regions with unsatisfactory observed climate simulations. Work capacity, and its relationship to the climate, depends on physical requirements (Table 1), and can be classified as either light, moderate, or heavy. Outdoor manual laborers who move about frequently or who are required to lift or carry heavy objects e.g. rural workers, sugarcane cutters, construction workers, etc., are those most affected.

According to NHO06, these workers have metabolic expenditure levels between 400 W to 526 W during their workday, but have exposure limits ranging between 25.4 and 26.1 units (FUNDACENTRO, 2017). Additionally, according to NR15 the maximum ESI exposure level is 25 units when working continuously without rest. According to a rule established by ACGIH in 2017, ESI values for workers not acclimatized should not exceed 30.5 units considering a metabolic expenditure in the order of 415 W for heavy work. The rules stress that heavy work must be followed by a work/rest cycle. The work cycle should not exceed 25% of the workday, and continuous work is not allowed (ACGIH, 2017).

Outdoor workers experience ESI levels smaller than 28 units according to the simulations for climate conditions between 1979 and 2005 (Figure 1). Brandão, Silva and Assireu (2013) corroborated these results. They showed that this group of workers might be subject to ESI values between 26 and 27.9 units. Under these conditions, according to the recommendations from NR 15 (Table 1), individuals performing hard work should work for 30 minutes per hour, followed by 30 minutes of rest in the shade. By contrast, ESI values in this order do not impact light work, but rather require 15 minute rests periods per hour of moderate activity. Compared to NHO06 (FUNDACENTRO, 2017), this would result in compatible metabolic expenditure levels for the work/rest cycles at 467 to 306 W. According to ACGIH (2017) heavy work should not be performed for 75 to 100% of the effective working time. At 27.5 units, ACGIH (2017) recommends that work be carried out 50 to 75% of the time. In practice this is difficult to apply, since in sugarcane harvesting, for example, which still uses nineteenth-century modes of harvesting, workers are paid according to their productivity. Under such conditions there are serious risks to worker health (ALVES, 2006).

In situations of ESI levels between 28 and 30 units, as indicated in the projections (CAT1 - Figure 2), NR 15 recommends breaks of 45 minutes in shade, every 15 minutes during heavy work activity. NHO06 states that working metabolic expenditures should be reduced to between 306 and 209 W. ACGIH (2017) states that heavy work is not be permitted in this range. There should be a work / rest regime in place to reduce the metabolic rate. Specifically, 28 units would correspond to 300 W and 30 units to 200 W.

According to NR15, when ESI levels are greater than 30 units (values also present in CAT1), workers cannot perform activities without employers providing adequate climate controls, such as cooling and ventilation systems. As of now, such systems cannot be applied in rural areas. Work should be stopped for at least 15 minutes every hour even when performing mild work. NHO06 stipulates that metabolic expenditure levels should be reduced to below 209 W, while ACGIH (2016) states that only work activities with work/rest cycles with weighted metabolic expenditure levels from 100 to 200 W are allowed. This corresponds to levels achieved when resting in a sitting position and while moving only one arm.

Using Kjellstrom's (2000) definition, NR 15 can be used to estimate work capacity for workers exposed to heat for each hour of the day. Considering the average daily data from the simulations, it is estimated that heavy work capacity - which is already 50% for climate conditions between 1979 and 2005 (ESI <28.0) - would drop to 25% in a best-case scenario ($28.0 \leq$ ESI ≤ 30.0), and to 0% in a worst-case scenario (ESI$>$ 30.0 units). Even lower metabolic performance activities may be affected under these conditions. These results do not imply that outside work cannot be performed at the end of this century, but rather draw awareness to the need to change current working conditions, e.g. changing working hours, using new technologies to reduce thermal stress and improve protection etc.

As the range of thermal stress areas in South America expands, and as the frequency of episodes per year increases, higher radiative forcing will result in the lower work capacity. Thus, whatever the future scenario, there is evidence that work capacity will be greatly reduced by the end of this century.

It is worth reiterating that the projection results use daily averages for the environmental variables considering all periods of the year. In other words, extreme values are lessened by considering averages. It stands to reason that real conditions may be even worse during the hottest times of the day and year. This reinforces the conclusion that outdoor work capacity will be reduced by the end of the 21st century, especially during the summer.

It is, however, important to highlight some uncertainties surrounding the simulations and projections in some categories of the thermal stress indices. There are uncertainties with respect to climate sensitivity, climate system numerical models, future CO_2 emissions, future population distribution, and technological and social changes (DUNNE; STOUFFER; JOHN, 2013). Furthermore, models cannot generate reliable data for regions with more complex climatic conditions. It is therefore difficult to model areas like the Amazon and the Andes. These regions have the largest biases for CMIP5 models (TORRES; MARENGO, 2014). This can occur due to the still rough spatial resolution of the models, among other factors (Torres, 2014).

Final considerations

The study evaluated the possible influence of climate change on outdoor working conditions in South America by comparing work capacity for climate conditions between 1979 and 2005, with future climate projections for 2071 to 2100.

The results show that work capacity for manual outdoor labor should fall to 25%, in the best-case scenario, and to 0 % in the worst-case scenario, when using average daily temperatures in the models. Under these conditions, outdoor manual labor activity should be reduced to at least 15-minute intervals, with a 45-minute rest period in the shade, according to NR 15. Moderate and light activity may also be affected, and will require minimum break times during work activity. ACGIH recommends that work/rest cycles should be organized to result in weighted metabolic expenditure levels of 200 W, corresponding to sitting work using only one arm. Considering a worst-case scenario, work regimes, as they are currently practiced, will not be possible at the end of the 21st century. This could result in serious socio-economic problem if not addressed.

The results of this study show that climate change may cause severe impacts on worker health and work capacity for manual laborers working outdoors. This may bring about negative impacts to national economies (EPSTEIN; MORAN, 2006). Projections precarious conditions for these workers, as thermal stress can result in adverse health conditions and reduced productivity. It is for this reason that more detailed assessments should be conducted to study working regimes in scenarios with less than eight hours of favorable working conditions. Due to the socioeconomic relevance of this issue, we propose that further studies evaluate using appropriate equipment and strategies for planning and optimizing labor productivity at different times of the day.

It is necessary to adapt labor conditions to minimize and mitigate adverse working conditions brought about by climate change. One alternative is to reduce fossil fuel consumption (IPCC, 2014a), but international efforts, such as the Paris Agreement, have so far been ineffective. Adaptation is, therefore, the only viable alternative. According to Kjellstrom, Lemke and Hyat (2011), the most effective mitigation technique for helping outdoor manual laborers is taking longer lasting rest periods during the workday. This would, however, decrease worker productivity, and more workers would have to be employed to maintain overall productivity.

Adaptation to climate change should be based on preventative measures such as urban planning, and rational work organization, the latter adapting work sites and work times. This may include increasing evening work hours or limiting early morning and late afternoon working hours, or changing work attire to facilitate thermal exchange between the body and the environment. Furthermore, legislation should be adapted to protect the physical and mental integrity of workers (DUNNE; STOUFFER; JOHN, 2013).

These actions may attenuate the effects of climate change on the workplace and promote the health and productivity of workers (KJELLSTROM; HOLMER; LEMKE, 2009). Decision makers, such as the government and entrepreneurs, need to implement actions to promote worker health and well-being.

Referências

ALVES, F. Por que morrem os cortadores de cana? **Saúde e Sociedade**, v. 15, n. 3, p. 90-98, 2006. Disponível em: <http://www.revistas.usp.br/sausoc/article/view/7496>. Acesso em: 15 jun. 2017.

AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS (ACGIH). ***Heat Stress and Strain: TLV® Physical Agents 7th Edition Documentation (2017).*** **TLVs and BEIs** with 7th Edition Documentation, CD-ROM. Cincinnati, OH, 2017.

BATIZ, E. C.; GOEDERT, J.; MORSCH, J. J.; JUNIOR, P. K.; VENSKE, R. Avaliação do conforto térmico no aprendizado: estudo de caso sobre influência na atenção e memória. **Revista Produção Online**, v. 19, n. 3, p. 477-488, 2009. Disponível em: <http://www.scielo.br/pdf/prod/v19n3/06.pdf>. Acesso em: 27 jan. 2016.

BITENCOURT, D. P.; FUENTES, M. V.; MAIA, P. A.; AMORIM, F. T. Frequência, duração, abrangência espacial e intensidade das ondas de calor no Brasil. **Revista Brasileira de Meteorologia**, v. 31, n. 4, 2016.

BITENCOURT, D. P.; RUAS, A. C.; MAIA, P. A. Análise da contribuição das variáveis meteorológicas no estresse térmico associada à morte de cortadores de cana-de-açúcar. **Caderno de Saúde Pública**, v. 28, n. 1, p. 65-74, 2012. Disponível em: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0102-311X2012000100007>. Acesso em: 27 mar. 2017.

BITENCOURT, D. P.; MAIA, P.A.; CAUDURO, R.R. The heat exposure risk to outdoor workers in Brazil. **Archives of environmental & occupational health**, p. 1-8, 2019.

BITENCOURT, D. P. Maximum wet'bulb globe temperature mapping in central–south Brazil: a numerical study. **Meteorological Applications**, v. 26, n. 3, p. 385-395, 2019.

BRANDÃO, L. V.; SILVA, L. P.; ASSIREU, A. T. Uso do índice de stress ambiental (IEA) para mapear regiões críticas quanto a exposição ao calor no estado de São Paulo: estudo de caso relacionado aos cortadores de cana-de-açúcar. **Hygeia**, v. 9, n. 16, p. 67-73, 2013. Disponível em: <http://www.seer.ufu.br/index.php/hygeia/article/view/20961/12453>. Acesso em: 18 jan. 2016.

BRASIL. Ministério do Trabalho e Emprego. Portaria n.º 3.214, de 08 de junho de 1978. **Norma Regulamentadora NR 15: atividades e operações insalubres**. Diário Oficial [da] República Federativa do Brasil. Brasília, DF, 6 jun. 1978. Disponível em: <https://enit.trabalho.gov.br/portal/images/Arquivos_SST/SST_NR/NR-15-Anexo-03.pdf>. Acesso em: 14 set. 2019.

CECCHERINI, G.; RUSSO, S.; AMEZTOY, I.; ROMERO, C. P.; CARMONA-MORENO, C. Magnitude and frequency of heat and cold waves in recent decades: the case of South America. **Natural Hazards and Earth System Sciences**, v. 16, n. 3, 821-831, 2016.

CHENG, V.; NG, E.; CHAN, C.; GIVONI, B. Outdoor thermal comfort study in a sub-tropical climate: a longitudinal study based in Hong Kong. **International Journal of**

Biometeorology, v. 56, n. 1, p. 43-56, 2012. Disponível em: <http://link.springer.com/article/10.1007%2Fs00484-010-0396-z>. Acesso em: 10 fev. 2016.

DJONGYANG, N.; TCHINDA, R.; NJOMO, D. Thermal comfort: A review paper. **Renewable and Sustainable Energy Reviews**, v. 14, n. 3, p. 2626-2640, 2010. Disponível em: <http://www.sciencedirect.com/science/article/pii/S1364032110002200>. Acesso em: 10 ago. 2015.

DONAT, M. G.; ALEXANDER, L. V.; YANG, H.; DURRE, I.; VOSE, R.; DUNN, R. J. H.; WILLETT, K. M.; AGUILAR, E.; BRUNET, M.; CAESAR, J.; HEWITSON, B.; JACK, C.; KLEIN TANK, A. M. G.; KRUGER, A. C.; MARENGO, J.; PETERSON, T. C.; RENOM, M.; ORIA ROJAS, C.; RUSTICUCCI, M.; SALINGER, J.; ELRAYAH, A. S.; SEKELE, S. S.; SRIVASTAVA, A. K.; TREWIN, B.; VILLARROEL, C.; VINCENT, L. A.; ZHAI, P.; ZHANG, X.; KITCHING, S. Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset. **Journal of Geophysical Research: Atmospheres**, v. 118, p. 2098-2118, 2013.

DUNNE, J. P.; STOUFFER, R. J.; JOHN, J. G. Reductions in labour capacity from heat stress under climate warming. **Nature Climate Change**, v. 3, n. 6, p. 563-566, 2013. Disponível em: <http://www.nature.com/nclimate/journal/v3/n6/full/nclimate1827.html>. Acesso em: 18 mar. 2017.

EPSTEIN, Y.; MORAN, D. S. Thermal comfort and the heat stress indices. **Industrial Health**, v. 44, p. 388-398, 2006. Disponível em: <https://www.jstage.jst.go.jp/article/indhealth/44/3/44_3_388/_pdf>. Acesso em: 25 jan. 2016.

FUNDACENTRO – Fundação Jorge Duprat Figueiredo de Segurança e Medicina do Trabalho. **NHO 06: avaliação da exposição ocupacional ao calor** [GIAMPAOLI, E.; SAAD, I. F. S. D.; CUNHA, I. A. (eds.)]. São Paulo, 46 pp., 2002. Disponível em: <http://www.fundacentro.gov.br/biblioteca/normas-de-higiene-ocupacional/publicacao/detalhe/2013/3/nho-06-avaliacao-da-exposicao-ocupacional-ao-calor>. Acesso em: 28 mar. 2017.

GEIRINHAS, J. L.; TRIGO, R. M.; LIBONATI, R.; COELHO, C. A.; PALMEIRA, A. C. Climatic and synoptic characterization of heat waves in Brazil. **International Journal of Climatology**, v. 38, n. 4, 1760-1776. 2018.

IPCC - Intergovernmental Panel in Climate Change. **Climate Change 2014: Impacts, Adaptation, and Vulnerability**. Summary for policymakers. Contribuição do Grupo de Trabalho II para o Quinto Relatório de Avaliação do Painel Intergovernamental sobre Mudanças Climáticas [FIELD, C. B.; BARROS, V. R.; DOKKEN, D. J.; MACH, K. J.; MASTRANDREA, M. D.; BILIR, T. E.; CHATTERJEE, M.; EBI, K. L.; ESTRADA, Y. O.; GENOVA, R. C.; GIRMA, B.; KISSEL, E. S.; LEVY, A. N.; MACCRACKEN, S.; MASTRANDREA, P. R.; WHITE, L. L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom e New York, NY, USA, 32 pp., 2014a. Disponível em: <https://ipcc-wg2.gov/AR5/images/uploads/WG2AR5_SPM_FINAL.pdf>. Acesso em: 20 jan. 2016.

IPCC - Intergovernmental Panel in Climate Change. **Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change** [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp

IPCC - Intergovernmental Panel in Climate Change. **Scenario process for AR5: Representative Concentration Pathways (RCPs)**. 2014b. Disponível em: <http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html>. Acesso em: 21 jan. 2016.

JUNIOR, L. C. S. C.; RAMOS, E. M. C.; TOLEDO, A. C.; CECCATO, A. D. F.; MACCHIONE, M.; BRAGA, A. L. F.; RAMOS, D. Avaliação da qualidade de vida relacionada à saúde de cortadores de cana-de-açúcar nos períodos de entressafra e safra. **Revista de Saúde Pública**, v. 46, n. 6, p. 1058-1065, 2012. Disponível em: <http://www.scielo.br/scielo.php?pid=S0034-89102012000600016&script=sci_abstract&tlng=pt>. Acesso em: 12 jun. 2016.

KJELLSTROM, T. Climate change, heat exposure and labour productivity. **Epidemiology**, v. 11, n. 4, p. S144, 2000. Disponível em: <http://journals.lww.com/epidem/Fulltext/2000/07000/Climate_change,_heat_exposure_and_labour.380.aspx>. Acesso em: 26 mar. 2017.

KJELLSTROM, T.; LEMKE, B.; HYAT, O. Increased workplace heat exposure due to climate change: a potential threat to occupational health, worker productivity and local economic development. **Asian-Pacific Newsletter on Occupational Health and Safety**, v. 18, n. 1, p. 5-11, 2011.

KJELLSTROM, T.; HOLMER, I.; LEMKE, B. Workplace heat stress, health and productivity - an increasing challenge for low and middle-income countries during climate change. **Global Health Action**, v. 2, 2009. Disponível em: <http://www.globalhealthaction.net/index.php/gha/article/view/2047>. Acesso em: 02 set. 2015.

LAMBERTS, R. **Conforto e Stress Térmico**. Universidade Federal de Santa Catarina – Centro Tecnológico – Departamento de Engenharia Civil. 2011. Disponível em: <http://www.labeee.ufsc.br/sites/default/files/disciplinas/ECV4200_apostila%202011.pdf_2.pdf>. Acesso em: 01 fev. 2015.

LEAMAN, A.; BORDASS, B. Assessing building performance in use 4: the Probe occupant surveys and their implications. **Building Research and Information**, v. 29, n. 1, p. 129–143, 2001. Disponível em: <http://www.tandfonline.com/doi/abs/10.1080/09613210010008045>. Acesso em: 27 jan. 2016.

LÉTARD, V.; FLANDRE, H.; LEPELTIER, S. (Comp.). **La France et les Français face à la canicule: les leçons d'une crise**: Rapport d'information n° 195 (2003-2004) fait au nom de la mission commune d'information, déposé le 3 février 2004. Paris: Le Sénat de La République Française, 2004. 391 p. Disponível em: <http://www.senat.fr/rap/r03-195/r03-195.html>. Acesso em: 27 jan. 2016.

LIDA, I. **Ergonomia: Projeto e Produção**. 2. ed. São Paulo: Edgard Blücher, 2005. cap. 16, p. 491-522.

MARENGO J. A.; RUSTICUCCI, M.; PENALBA, O.; RENOM, M. An intercomparison of observed and simulated extreme rainfall and temperature events during the last half of the twentieth century: part 2: historical trends. **Climatic Change**, v. 98, p. 509-529, 2010.

MORAN, D. S.; PANDOLF, K. B.; EPSTEIN, Y.; HELED, Y.; SHAPIRO, Y.; GONZALEZ, R. R. Validation of the environmental stress index (ESI) for physiological variables. **Eslsevier Ergonomics Book Series**, v. 3, p. 495-501, 2005. Disponível em: <http://www.sciencedirect.com/science/article/pii/S1572347X05800771>. Acesso em: 05 fev. 2016.

MORAN, D. S.; PANDOLF, K. B.; SHAPIRO, Y.; HELED, Y.; SHANI, Y.; MATHEW, W. T.; GONZALEZ, R. R. An environmental stress index (ESI) as a substitute for the wet bulb globe temperature (WBGT). **Journal of Thermal Biology**, v. 26, n. 4-5, p. 427-431, 2001. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0306456501000559>. Acesso em: 05 fev. 2016.

MOSS, R. H.; EDMONDS, J. A.; HIBBARD, K. A.; MANNING, M. R.; ROSE, S. K.; VAN VUUREN, D. P.; CARTER, T. R.; EMORI, S.; KAINUMA, M.; KRAM, T.; MEEHL, G. A; MITCHELL, J. F. B.; NAKICENOVIC, N.; RIAHI, K.; SMITH, S. J.; STOUFFER, R. J.; THOMSON, A. M.; WEYANT, J. P.; WILBANKS, T. J. The next generation of scenarios for climate change research and assessment. **Nature**, v. 463, n. 11, p. 747-756, 2010. Disponível em: <https://www.researchgate.net/publication/41422439_The_Next_Generation_of_Scenarios_for_Climate_Change_Research_and_Assessment>. Acesso em: 21 jan. 2016.

PALLOTTA, M.; HERDIES, D. L.; GONÇALVES, L. G. G. Estudo das condições de tempo e conforto térmico no desempenho esportivo aplicado à maratona na cidade do Rio de Janeiro. **Revista Brasileira de Meteorologia**, v. 30, n. 2, p. 223-240, 2015. Disponível em: <http://www.scielo.br/pdf/rbmet/v30n2/0102-7786-rbmet-30-02-00223.pdf>. Acesso em: 04 fev. 2016.

PBMC, 2014: Base científica das mudanças climáticas. Contribuição do Grupo de Trabalho 1 do Painel Brasileiro de Mudanças Climáticas ao Primeiro Relatório da Avaliação Nacional sobre Mudanças Climáticas [Ambrizzi, T., Araujo, M. (eds.)]. COPPE. Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brasil, 464 pp

SALVIANO, M. F.; GROPPO, J. D.; PELLEGRINO, G. Q. Análise de tendências em dados de precipitação e temperatura no Brasil. **Revista Brasileira de Meteorologia**, v. 31, n. 1, p. 64-73, 2016.

SOUZA, P.M.B. Estresse térmico em trabalhadores expostos ao ar livre: Perspectivas para o século XXI. Dissertação de Mestrado. Programa de pós-graduação em meio ambiente e recursos hídricos. 2017. 91 p.

STERNER, T. Higher costs of climate change. **Nature**, v. 527, n. 7577, p. 177-178, 2015. Disponível em: <http://www.nature.com/nature/journal/v527/n7577/full/nature15643.html>. Acesso em: 20 mar. 2017.

TORRES, R. R. **Análise de incertezas em projeções de mudanças climáticas na América do Sul**. 2014. 239 p. Dissertação de Doutorado do Curso de Pós-Graduação em Meteorologia, Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 2014. Disponível em: <http://urlib.net/8JMKD3MGP7W/3FHR358>. Acesso em: 02 ago. 2016.

TORRES, R. R.; MARENGO, J. A. Climate change hotspots over South America: from CMIP3 to CMIP5 multimodel datasets. **Theoretical and Applied Climatology**, v. 117, p. 579-87, 2014. Disponível em: <https://link.springer.com/article/10.1007/s00704-013-1030-x>. Acesso em: 04 dez. 2017.

VAN VUUREN, D. P.; EDMONDS, J.; KAINUMA, M.; RIAHI, K.; THOMSON, A.; HIBBARD, K.; HURTT, G. C.; KRAM, T.; KREY, V.; LAMARQUE, J-F.; MASUI, T.; MEINSHAUSEN, M.; NAKICENOVIC, N.; SMITH, S. J.; ROSE, S. K. The representative concentration pathways: an overview. **Climatic Change**, v. 109, n. 1, p. 5-31, 2011. Disponível em: <http://link.springer.com/article/10.1007%2Fs10584-011-0148-z#/page-1>. Acesso em: 21 jan. 2016.

VILELA, R. A. G.; LAAT, E. F.; LUZ, V. G.; SILVA, A. J. N.; TAKAHASHI, M. A. C. Pressão por produção e produção de riscos: a "maratona" perigosa do corte manual da cana-de-açúcar. **Revista Brasileira de Saúde Ocupacional**, v. 40, n. 131, p. 30-48, 2015. Disponível em: <http://www.scielo.br/pdf/rbso/v40n131/0303-7657-rbso-40-131-30.pdf>. Acesso em: 24 jun. 2017.

WEEDON, G.P.; BALSAMO, G.; BELLOUIN, N.; GOMES, S.; BEST, M.J.; VITERBO, P. The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data. **Water Resources Research**, v. 50, n. 9, p. 7505-7514, 2014. doi:10.1002/2014WR015638.

WILSON, T. E.; CRANDALL, C. G. Effect of Thermal Stress on Cardiac Function. **Exercise and sport sciences reviews**, v. 39, n. 1, p. 12-17, 2011. Disponível em: <https://www.ncbi.nlm.nih.gov/pubmed/21088607>. Acesso em: 16 mar. 2017.

ZANDER, K. K.; BOTZEN, W. J. W.; OPPERMANN, E.; KJELLSTROM, T.; GARNETT, S. T. Heat stress causes substantial labour productivity loss in Australia. **Nature Climate Change**, v. 5, n. 7, p. 647-651, 2015. Disponível em: <http://www.nature.com/nclimate/journal/v5/n7/full/nclimate2623.html>. Acesso em: 21 mar. 2017.

ZHAO, Y.; DUCHARNE, A.; SULTAN, B.; BRACONNOT, P.; VAUTARD, R. Estimating heat stress from climate-based indicators: present-day biases and future spreads in the CMIP5 global climate model ensemble. **Environmental Research Letters**, v. 10, n. 8, p. 1-12, 2015. Disponível em: <http://iopscience.iop.org/article/10.1088/1748-9326/10/8/084013>. Acesso em: 13 abr. 2016.

Submitted on: 21/04/2018
Accepted on: 20/11/2019
http://dx.doi.org/10.1590/1809-4422asoc20180011r3vu2020L1AO
2020;23:e00113
Original Article

INFLUENCE OF CLIMATE CHANGE ON WORKING CONDITIONS IN THE LATE 21ST CENTURY

PLÍNIO MARCOS BERNARDO DE SOUZA
MARCELO DE PAULA CORRÊA
ROGER RODRIGUES TORRES
LUIZ FELIPE SILVA

INFLUENCE OF CLIMATE CHANGE ON WORKING CONDITIONS IN THE LATE 21ST CENTURY

***Abstract*:** The adverse effects of climate change may affect work conducted outdoors. For this reason, this study seeks to evaluate these effects by comparing South American work capacity under climate conditions between 1979 and 2005, as well as expected future climate scenarios from 2071 to 2100. Thermal stress was estimated using the Environmental Stress Index (ESI), based on atmospheric variables for climate projections from the Intergovernmental Panel on Climate Change (IPCC). The results indicate that, even in favorable climate scenarios, outdoor manual labor capacity will be reduced by 25 to 50% by the end of the 21st century in basically all of South America, especially in the Amazonian regions, parts of the north and northeast of Brazil, and in vast regions from Paraguay to Suriname. There is an overall pessimistic outlook with respect to outdoor working conditions during common labor hours due to increases in the greenhouse effect.

Keywords: Thermal Stress, Work Capacity, Climate Change, Outdoor Work.

INFLUÊNCIA DAS MUDANÇAS CLIMÁTICAS SOBRE AS CONDIÇÕES DE TRABALHO NO FINAL DO SÉCULO XXI

***Resumo*:** Os efeitos adversos das mudanças climáticas devem atingir o trabalho ao ar livre. Por esse motivo, o objetivo deste estudo é avaliar esses efeitos comparando-se a capacidade de trabalho na América do Sul entre clima presente (1979 a 2005) e o futuro (2071 – 2100). O estresse térmico foi estimado por meio do *Environmental Stress Index* (ESI), com base em variáveis atmosféricas provenientes das projeções climáticas do IPCC. Os resultados indicam que, mesmo em cenários climáticos favoráveis, a capacidade de trabalho pesado deve ser reduzida entre 25 a 50% no final do século XXI em praticamente toda a América do Sul, principalmente na região Amazônica, partes do norte e nordeste brasileiros, além de extensas regiões do Paraguai ao Suriname. Assim, cenários pessimistas, com intensificação do efeito estufa, podem implicar em falta de condições ambientais e físicas para trabalhos dessa natureza em horários atualmente comuns para a atividade laboral.

***Palavras-chave*:** Estresse Térmico, Capacidade de Trabalho, Mudanças Climáticas, Trabalho ao Ar Livre.

INFLUENCIA DEL CAMBIO CLIMÁTICO EN LAS CONDICIONES LABORALES A FINES DEL SIGLO XXI

***Resumen*:** Los efectos adversos del cambio climático deberían afectar el trabajo al aire libre. Por esta razón, el propósito de este estudio es evaluar estos efectos comparando la capacidad de trabajo en América del Sur entre el clima actual (1979 a 2005) y el futuro (2071 - 2100). El estrés térmico se estimó utilizando el Índice de Estrés Ambiental (ESI), basado en variables atmosféricas de las proyecciones climáticas del IPCC. Los resultados indican que, incluso en escenarios climáticos favorables, la capacidad de servicio pesado deberá reducirse entre un 25 y un 50% para fines del siglo XXI en prácticamente toda Sudamérica, especialmente en la región amazónica, partes del norte y noreste de Brasil, y desde extensas regiones desde Paraguay hasta el Surinam. Por lo tanto, los escenarios pesimistas, con la intensificación del efecto invernadero, pueden implicar una falta de condiciones ambientales y físicas para el trabajo de esta naturaleza en las horas de trabajo habituales actualmente.

***Palabras clave*:** estrés térmico, capacidad de trabajo, cambio climático, trabajo al aire libre.