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Climate change impact on microclimate of work environment related to occupational health and productivity

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Abstract
Introduction. Climate change is a global emergency that influences human health and occupational safety. Global warming characterized by an increase in temperature of the ambience and humidity affects human health directly impairing body thermoregulation with serious consequences: dehydration, fatigue, heat stroke and even death. Several studies have demonstrated negative effects of climate change on working populations in a wide variety of workplaces with particular regard to outdoor and uncooled indoor workplaces. Most vulnerable workers are outdoor workers in tropical and subtropical countries usually involved in heavy labor during hot seasons. Many of the consequences therefore, regarding working people are possible, even without health symptoms by reducing work productivity.
Aim. The scope of this review is to investigate effects of climate change on workers both in relation to health and work productivity.
Methods. This study has been realized by analyzing recent international literature.
Conclusions. In order to reduce negative effects of climate change on working populations it is essential to implement preventive measures with a multidisciplinary strategy limiting health risks and improving work productivity.

Key words
- climate change
- occupational health
- heat stress disorders
- hot temperature
- body temperature regulation

INTRODUCTION

The Earth is going through a period of climate change characterized by the increase of the average ambience temperatures and humidity [1-3]. Global climate change, both anthropic and/or naturally occurring, are predicted to increase average world temperatures by about 2-4 °C during this century [4, 5]. The rise in average temperatures is related to the increase of atmospheric concentration of greenhouses gases, as it has been derived from the analysis of the Vostok ice core. This, in turn, will contribute to the rise of the average temperature. Widespread changes in extreme temperatures have been observed over the last 50 years. Cold days, cold nights have become less frequent, while hot days, hot nights, heat waves, local storms, precipitations have become more frequent particularly during the last 10 years [1, 4, 6]. Human beings are directly exposed to climate change (heat stress, tiredness and exhaustion, eventual death) and indirectly through changes in the ranges of disease vectors, waterborne pathogens, water quality and supply, air quality, food quantity and quality, ecosystems, agriculture [1, 2]. The evidence of negative consequences from climate change on human health is unequivocal [7, 8], and serious health effects are growing with regards to working people such as heat exhaustion and heat stroke [7, 9]. Nevertheless the relation between climate change and health is a relatively new research field that has a number of gaps in current evidence and needs more insights [7].

This review provides a report about the effects of heat stress on the working population as due to climate change, to assess the impact on occupational health and safety in many outdoor and indoor workplaces.

Main sectors that are directly affected by climate change are agriculture, industry, fisheries, forestry, small and medium sized enterprises. Outdoor workers are the most vulnerable [7, 10].

Workers in tropical and subtropical regions, many of whom are involved in heavy physical work outdoors or indoors without effective cooling, are at a particularly high risk [11]. Workers in temperate regions are also at an increased risk of heat stress, especially during heat waves [11, 12].

It has also been published in some studies that workers are exposed to unacceptably high temperatures and humidity in work situations that cannot be modified,

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which cause serious health effects (heat strain and heat stroke) and reduction of labor productivity and work capacity [13, 14].

Many studies predict that global climate change will increase average temperatures [15, 16], as well as shift of the distribution of the daily peak temperature and relative humidity so that heat episodes will become more frequent and extreme. These effects will contribute reducing the work capacity and productivity [13].

However, current knowledge is limited in many areas, so an increase in research in this sector could provide a very important means to improve prevention strategies reducing the health risk and increasing work productivity.

THERMOREGULATION

The temperature of the human body is an important indicator of its condition [17]. Body temperature is far from being homogeneous. Roughly, it is possible to single out three body temperature areas: the core, the shell and the skin. The core is composed by sensitive organs: thoracic organs, abdominal organs and the brain; it has a temperature of 37 ± 1 °C. The shell is 2 °C to 4 °C cooler than the core and is made up of arms and legs. Lastly there is the skin which is the interface with the environment and is even cooler than the shell. Unlike core temperature, which is tightly regulated, skin temperature varies markedly as a function of environmental exposure; temperature of peripheral tissues depends on current exposure, exposure history, core temperature, and thermoregulatory vasomotion. Core temperature, while by no means completely influencing body heat content and distribution, nevertheless is the best single quantity that is used as an indicator of thermal status in humans [18]. Humans can survive a core temperature decrease of 10 °C, but only an increase of 5 °C [19]. In order to perform a more accurate preservation of core temperature a two-step regulation occurs. The core exchange heat with blood vessels that split into capillaries that, in turn, interface with the environment. The thermoregulation occurs when receptors, sensitive to temperature change send messages via the Central Nervous System to the hypothalamus where the regulation occurs. The mechanism of the heat exchange of the body is convection, conduction, irradiation and sweating. All these processes are mediated by the blood circulatory system that transports heat from the core to the skin, or vice versa, depending on the temperature change in the regulatory system. Thermal radiation emitted by the body is rather constant. Conduction and convection, which depend on temperature gradient of the environment, are bootstrapped by sweating evaporation. But even evaporation can be weakened if the surroundings have a high percentage of relative humidity.

The ultimate control and co-ordination of thermoregulation in humans is performed by the autonomic system, which is that part of the neural system that controls those body functions that are not under voluntary control [17].The heat/cold perception is mediated by the sensorineural system. The temperature is sensed by nerve endings, the thermoreceptors, which, when stimulated, send signals to the hypothalamus at the base of the brain. The anterior hypothalamus, described as the "heat loss center," provides thermoregulation when the body is too hot. It combines the function of temperature sensor and controller; any rise in temperature above the set point of the anterior hypothalamus causes it to send out efferent nerve impulses to initiate the body's heat loss mechanisms of vasodilatation and sweating. The set point is normally 37 °C but is raised during exercise or fever. The posterior hypothalamus or "heat maintenance center" provides defense against cold. Keller and Hare show that after destruction of the heat maintenance center, the heat loss functions (of the heat loss center) remain intact; therefore, we know that the heat loss function is independent from the heat maintenance function. The heat maintenance center mainly receives temperature signals from the skin sensors. The resulting efferent responses are vasoconstriction and shivering [20].

IMPACT OF CLIMATE CHANGE ON WORKERS' HEALTH

Climate change is any significant variation in temperature, precipitation, wind, or other type of weather that lasts for decades or longer. These changes can affect human health in several direct and indirect ways.

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Extreme Events (SREX) stated that it is very likely that there has been an overall decrease in the number of cold days and nights, and an overall increase in the number of warm days and nights, on the global scale. The same report acknowledges some evidence of heat stress, death, or injury in floods and storms, as human health is directly affected by climate change [21]. Actually, it is well known that if the body temperature rises above 38°C physical and cognitive functions are impaired; when body temperature exceeds 39 °C acute heat disorders (heat stroke) may occur, and above 40.6 °C life threatening "severe hyperpyrexia" occurs (risks of organ damage, loss of consciousness and death increase sharply) [14].

Physical work in a hot environment may rise body heat production from about 1 kcal/min to a maximum of 20 kcal/min. This heat production can theoretically increase core temperature by 1 °C every 5 to 7 min. So, working in a hot environment may lead to a rise in the number of cases of heat-related illnesses such as heat stroke or heat exhaustion, decreased chemical tolerance and fatigue. If cooling via sweating, irradiation, conduction and convection cannot keep up with metabolic heat production, the core body temperature will rise above 38 °C. This will have progressively negative effects on the human body and will induce excessive dehydration, which is a major cause of symptomatic exhaustion and clinical diseases.

Moreover, there may be indirect effects on workers' safety of insufficient cooling that includes reduced vigilance, increased risk of injury and irritability (that may lead to carelessness). Heat can also increase other risks of injury in workers as it may result in sweaty palms, fogged-up safety glasses and dizziness. Burns may also occur because of accidental contact with hot surfaces or steam when there are environmental heat screen hot spots.

If heat induces negative effects to worker's health and productivity a number of worker populations will be particularly vulnerable to threats from climate change when the total heat load exceeds the capacities of the body to maintain a core body temperature of 37 °C and the normal body functions without excessive strain [1, 22].

It's evident that mostly workers in a hot or outdoor environment are exposed to risks from heat stress such as firefighters, bakery workers, farmers, construction workers, miners, boiler room workers, steel factory workers, and others. Negative consequences for indoor workers exposed to heat stress have been demonstrated in such workplaces as greenhouses, glass or rubber manufacturing plants, and for others who work in buildings without air conditioning or proper ventilation systems [1].

In many parts of the world ongoing climate change during the last three decades has produced higher temperatures and occupational heat stress levels in both outdoor and indoor workplaces. In tropical and sub-tropical countries working people are particularly exposed to occupational heat stress risk because of excessive workplace heat exposures linked to the outdoor ambience and the lack of thermal environmental optimal controls. Heat waves in cooler countries are also affecting workers' health and productivity if we consider that people are less used to a warmer climate. Workers in large cities may experience greater heat exposure, compared to their rural counterparts, as a result of urban heat island effects [11, 23, 24].

A recent Centers for Disease Control and Prevention (CDC) report identified, during 1992-2006, a total of 423 worker deaths from exposure to environmental heat were reported in the United States. Of these 423 deaths, 102 (24%) occurred in workers employed in the agriculture, forestry, fishing, and hunting industries (rate: 0.16 per 100 000 workers), as shown in *Table 1* [25]. Besides, over the past 30 years, more than 100 football players (both professional and college players) have died from thermal stress during practice and competition. This was thought to depend on insufficient awareness of the relevance of heat stroke *(Table 1)* [19].

The impact of climate change on workers' health, both as local increases in mean temperatures and frequencies of heat events, interacts also with other factors. For instance, in literature population growth, energy policies, energy saving policies (lack of controls such as shade, fans, air-conditioning and other adaptive capacities), working policies (more intense physical work demands and/or fewer drinking rest breaks) and increasing urbanization and deforestation have been taken into account. Work-related factors such as work practices, work/rest cycles, access to water and access to shade/cooling and other controls should also be considered as impacting on the increase of heat-induced disorders. Another very important factor that influences thermal stress is individual susceptibility: age; weight; degree of physical fitness; degree of acclimatization; metabolism; use of alcohol or drugs; a variety of medical conditions such as hypertension or thyroid disease; prior heat injury; and the type of clothing worn [1].

It means that the occurrence of these factors together with climate change may lead to a raise in magnitude and severity of known hazards and result in increasing numbers of workers who would be exposed to them.

Based on previous considerations it is necessary to implement appropriate heat stress management measures to prevent dangerous effects from worker heat stress.

Table 1
Number of occupational deaths from heat stroke and heat stress among workers

Characteristic	No.	References
Total	**68***	*MMWR Report* 2008 [25]
Industry category		
Crop production	52	
Vegetable and melon farming	15	
Fruit and tree nut farming	11	
Other crops	19	
Other/unspecified	7	
Support activities	16	
Professional sportsmen		Mc Ardle *et al.* 2015 [19]
Football players	> 100	
Unspecified	49	*IRSST Report* 2013 [28]

*Per 100 000 workers.

IMPACT OF CLIMATE CHANGE ON WORKERS' PRODUCTIVITY

Environmental conditions may directly influence work productivity, in particular for those activities that need physical work. A new research, in relation to climate change, cannot elude including an analysis of how global warming will affect the productivity and work capacity of people who are exposed to thermal stress. Heat stress is limited, usually, to the hottest parts of the day in the hottest seasons, but in many outdoor workplaces and uncooled indoor workplaces in tropical and sub-tropical regions this happens for a large part of the year and regards outdoor workers and many indoor workers without air conditioning [26].

Strong physical activity and workplace heat exposure affect synergistically work capacity and productivity [27]. Many studies highlight work productivity problems suffered by people who carry out physical work (especially agricultural work) when exposed to excessive heat conditions. When work conditions are very stressful and involve heavy work intensity, the workers adopt a self-placed defense mechanism. In these cases the work productivity per hour gradually decreases with the increase in heat exposure and the work activity must be slowed down [14, 26, 27].

Several recent studies pointed out different effects of extended heat exposure on work productivity. It was seen that, in uncooled indoor environments, increased heat exposure decreases performance [14]. While, adopting technical solutions (traditional air conditioning or innovative low cost solutions as solar powered system) will reduce humidity and temperature and increase productivity, especially in hot and humid indoor workplaces (offices) in developing countries [10]. The relationship between work performance and heat stress is complex. In the case of physical tasks high temperatures affect worker skills which result in a decline of work capacity, productivity and safety. Heat stress can alter motor performance (manual dexterity) producing detrimental effects on motor response, and since most cognitive tasks require a motor response, some cognitive deficiencies may be attributed to decreased motor performance [28, 29]. Proven evidence shows that mental tasks are differentially sensitive to heat stress. Recent studies confirm that complex cognitive tasks (vigilance) are more vulnerable than simple cognitive tasks to thermal stress [29]. When body temperature increases, it can also alter emotional state (irritability, anger) reducing vigilance and extending reaction times with consequences on occupational safety in the case of dangerous tasks [28, 29].

Many studies show that changes in temperature of a few degrees Celsius can affect mental performance in several complex tasks including: typewriting, vigilance, driving, reaction time, signal recognition and memory [30].

It has been estimated that approximately a 7% increase in productivity is present in a workplace maintained at the population-average neutral temperature between 20-24 °C. It has also been estimated that productivity is affected after approximately one hour of moderate physical work in temperatures above 32 °C [10].

Linkage between heat exposure and productivity losses in most vulnerable workers have been widely studied. Several studies based on the Hothaps-Soft database and software and Climate. CHIP.org website indicates that in South-east Asia as much as 15% to 20% of annual work hours may already be lost in heat-exposed jobs, and this may be doubled by 2050 as global climate change progresses [26].

In a study by Kjellström *et al.*, 2009, in terms of absolute change in labor productivity by the 2080, the greatest absolute losses (11.4% to 26.9%) are foreseen in Southeast Asia, Andean and Central America, Eastern Sub-Saharan Africa and the Caribbean. Eastern and Western Europe and Southern Latin America will have the smallest losses (0.1% to 0.2%); the combined effects of less warming and greater wealth (people work in less labor-intense jobs) result in a considerably smaller impact in all regions (the greatest loss being 16% in Central America) [10, 13].

It seems evident, according to previous considerations, that the effects of climate change must be understood not only as health implications but also as economic damages because of work productivity reduction.

CONCLUSIONS

Summing-up, this paper has shown that global climate change affects workers' health and productivity. During the last three decades the rise in the average temperature and the increase of frequencies of heat events in combination with other factors (individual susceptibility, work factors) has led to a rise in the severity of health hazards (heat stroke, death). Most vulnerable workers are outdoor workers in tropical and subtropical countries exposed to excessive heat conditions and involved in heavy labor, but the negative effects also regard uncooled indoor workers. Many effects of climate change on workers are possible even without health symptoms, especially in work capacity and productivity. Recent studies have indicated that when workers are exposed to extended heat stress and employed in heavy physical activities, work skills are affected, and therefore there is a decrease in the work capacity and productivity. In particular the reduction of cognitive tasks (vigilance) and the extension of reaction times results in decline of work safety in the case of dangerous tasks (pilots, drivers). Because of this evidence, it is fundamental to implement preventive measures with a multidisciplinary approach based on effective control strategies to reduce dangerous effects on worker's health and improve work productivity. More studies are needed regarding how the climate changes influence occupational heat stress risks and work productivity through the knowledge of different disciplines (climatology, medicine, epidemiology).

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Conflict of interest statement

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