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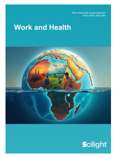

Perspective

The Burden of Extreme Humidity on Outdoor Workers in a Warming Planet

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Abstract: Global warming is the prime existential issue facing our planet. Accordingly, there can be no greater public health concern than the need to maintain economic activity while protecting workers directly exposed to solar radiation. Since mining, agriculture, construction, and sport and recreation inevitably involve solar exposure, climate change portends a decreasing number of days and hours when workers in these industries can be both productive and free of risk of heat illness. The implications are especially profound in those parts of the globe where humidity levels are predicted to exceed the limits of human tolerance.

Keywords: global warming; outdoor work; heat stress; humidity

Despite uncertainties in the rate and extent of future global warming, the underlying physics is beyond dispute.

The trapping of infrared radiative energy by the atmosphere was first reported by Fourier in 1827 [1], and in 1862 Tyndall reported his discovery that the principal agents responsible for heat trapping were relatively minor components of the atmosphere—carbon dioxide and water vapour [2].

An increase in CO_2 levels, following what is known as the Keeling Curve, has been recorded at the Mauna Loa Observatory in Hawaii, from 315 ppm in 1958 to the current 427 ppm, compared with pre-industrial era CO_2 levels, which are estimated to have been relatively constant at 280 ppm. In 2020, the Hadley Centre and Climatic Research Unit estimated that the mean global temperature has risen between 1 °C and 1.5 °C in the period 1850 to 2018, by a greater amount in the Northern Hemisphere than in the Southern Hemisphere [3]. The Copernicus Climate Change Service, an agency of the European Union, reports that 2024 was 0.72 °C warmer than the 1991–2020 average, and 1.60 °C warmer than the pre-industrial level, making it the first calendar year to exceed 1.5 °C above pre-industrial levels [4].

The rise in temperature induced by CO_2 has increased the atmospheric water vapour concentration. According to the Clausius-Clapeyron Relation, at a temperature of 300 °Kelvin (27 °C), an increase of 1 °K will cause a 6% increase in water vapour pressure. This is consistent with empirical findings that the total water vapour in the atmosphere has been increasing by about 1% every 10 years [5]. Water vapour has a greenhouse effect even greater than that of CO_2, so there is an amplifying effect on the warming from CO_2. It is estimated that the additional effect of water vapour will be, at least, nearly to double the warming effect of CO_2 alone [6]. Overall, considering other factors such as the melting of snow and ice increasing absorption of solar energy, a doubling of CO_2 is expected to increase global mean temperature by about 2.5 °C, although the incomplete understanding of the effect of clouds creates some uncertainty around this estimate.[7].

Accompanying rising temperatures is an increase in the frequency of extreme heat events [8].

The significance of this degree of global warming and the steep rise in the number of days of extreme heat is profound for people undertaking physical work, especially in activities necessitating exposure to solar radiation such as construction, mining and agriculture as well as sports and recreation. Where ambient temperature exceeds skin temperature of 35 °C, radiant and convective heat loss becomes negative, and prevention of heat storage and hyperthermia becomes solely dependent on evaporation of sweat. As the evaporative sweat requirement reaches capacity, heat storage and hyperthermia can only be avoided by reducing the work rate. Thus, the most important measure for preventing occupational heat strain is behavioural, that is self-pacing, whereby the worker—consciously or unconsciously—reduces work rate in response to perceived heat stress. In extreme conditions all physical activity must cease.

There is a further risk to the level of productive work that can be performed in extreme conditions: fewer available workers. The effects of heat stress on people with co-morbid conditions is already clear from studies of populations experiencing heat waves. Of the increased deaths and hospital presentations, only a minority of cases are coded as heat-related conditions. What is observed is increased mortality and hospitalisations from heart disease, lung disease, stroke, and renal disease [9,10]. Clearly anybody with any of these conditions would be ineligible to work under extreme heat conditions.

The potential workforce will be further limited by the current epidemic of obesity. Overweight people tend to have a lower body surface area relative to their mass. The resulting limitation of maximum sweat capacity puts fat people at high risk from working in heat.

Intake of some medications presents a further barrier to working in heat. This restriction is not solely from prescription medication. In a US study of work-related cases of severe hyperthermia (fatal and non-fatal), toxicology results were available in 34. No fewer than nine of these cases tested positive for amphetamine-like substances, of which only two had been legally prescribed [11].

With global warming the primary existential concern facing the planet, there cannot be a more pressing issue to occupational health and safety practitioners than how to maintain a sustainable level of economic activity without putting workers at risk of heat-related illness.

The first measure in the hierarchy of controls, elimination of the hazard at source, is a major challenge. Even the most committed governments are facing difficulties in eliminating the combustion of fossil fuels, and now this objective has suffered a severe setback with the world's largest economy now intent on repeal of climate action policies.

As well as the basic measures to protect workers in hot conditions such as maintaining hydration, allowing time for acclimatisation, provision of shade and ventilation, some additional steps should be standard in extreme conditions. A minimum requirement is to record the environmental parameters—dry-bulb and wet-bulb temperature, mean radiant temperature, air velocity and clothing insulation value—to determine an appropriate work-rest schedule. A number of indices have been developed for this purpose, the most widely used being the Wet-bulb Globe Temperature index (WBGT). More advanced models that have undergone validation include the UTCI-Fiala model [12] and the Australian-designed Thermal Work Index (TWI) [13]. Based on the environmental measurements, these indices generate work-rest schedules designed to protect most workers from adverse effects.

The work limits for these heat stress indices are recommended on the assumption that workers are adequately hydrated and self-paced, with more restrictive work limits for unacclimatised workers. As mentioned, self-pacing is the most effective measure to prevent adverse effects of heat stress, but it cannot be guaranteed that every worker will reduce their work rate to avoid heat storage. In some circumstances self-pacing is compromised when individuals suppress the instinct to slow their work rate. This is of course intrinsic in competitive sports, but it can also occur in the workplace, for example as a result of the monetary incentive of piecework. Peer pressure may also inhibit some workers from reducing their work rate. In a study of 13 work-related fatalities from heat stress in Australia, 7 deaths occurred in the worker's first week of employment [14]. Although lack of acclimatisation might have been a contributing factor, newly hired workers may be sensitive to peer pressure to maintain the same work rate as their peers.

Therefore even when a thermal stress index has been used to derive a work-rest schedule, it should not be taken for granted that all workers are protected. Testing of these heat stress indices has shown that some excursions of body core temperature (T_c) above the prescribed limit can still occur, notwithstanding compliance with the work schedule and allowing for self-pacing [15,16]. It is therefore desirable that even where work schedules are observed according to prescribed standards, some physiological monitoring be undertaken also. The recommended physiological markers are T_c and cumulative sweat loss. ISO standard 7933 recommends that to protect most workers from adverse effects, T_c should not exceed 38.0 °C, although a more liberal standard of 38.2 °C has been suggested and is indeed used for the TWI [17]. Tympanic temperature is a convenient minimally invasive proxy for T_c.

The Added Burden of Extreme Humidity

In some parts of the world, there is a further dimension of concern: the prospect of extreme humidity. As mentioned, when ambient temperature exceeds skin temperature, radiant heat loss and convective heat loss cease, and evaporation of sweat is the sole means of shedding metabolic heat. As humidity approaches saturation levels, sweat evaporation is impaired, and if the wet-bulb temperature (T_w) reaches skin temperature, that is 35 °C, the body cannot cool itself and heat storage occurs.

In 2010 Sherwood and Huber proposed a T_w of 35 °C as a peak level of heat stress beyond which the human body cannot survive beyond a limited time. They estimated that even at rest, T_c under such conditions would increase from 37 °C to 42 °C in about 4 hours. They noted that while these extremes of humidity had not occurred (indeed that at that time, T_w had never exceeded 31 °C) they could be expected if global mean temperature were to increase by 7 °C. [18]. The latter forecast turned out to be optimistic: subsequent observations have indicated that these conditions will occur at much lower global mean temperatures. In 2020, Raymond et al. found that some coastal subtropical locations have already reported T_w of 35 °C, albeit for only 1–2 h duration. Overall exceedances of extreme heat (T_w 27 °C and above) were found to have more than doubled since 1979 [19].

Subsequently, Vecellio et al. have shown by empirical testing on young, healthy adults that uncompensable heat stress in humid environments occurs at T_w levels of 30 °C to 31 °C, significantly below the 35 °C proposed as critical by Sherwood and Huber. Although subjects' T_c levels were below those associated with heat stroke, they rose continuously at these lower T_w levels, implying uncompensated heat stress [20]. Moreover, the subjects in this study were engaged in low-level physical activity designed to characterise the activities of daily living, It follows that for people undertaking physical work, uncompensated heat stress would be expected at even lower T_w levels.

More recently, Vecellio et al. have predicted that should global temperatures rise by more than 2 °C, populations in sub-tropical areas will experience conditions above these empirically determined limits. These locations, sub-Saharan Africa, the Indus River valley, eastern China and the Persian Gulf, encompass countries with high population density and are largely agrarian economies, mandating work with exposure to direct sunlight. In the near future, such exposures are likely to be brief, so that some physical work may be possible. [21].

Adaptive strategies will be needed if any work is to be performed in extreme humid heat. They would include scheduling work to hours outside those where heat is below maximum levels. Another measure is to increase the efficiency of physical work (i.e., increasing the proportion of metabolic activity converted to physical work and reducing the proportion converted to heat). This would involve mechanisation where possible. Where mechanisation is impracticable, skills training can help physical tasks to be performed with economy of effort. For those not required to work outside, air-conditioning can provide protection against extreme heat and humidity, but these areas include countries which are not affluent, so there would be difficulties in protecting large populations. Moreover, the commonly used evaporative cooling is ineffective in humid conditions.

Should global mean temperatures increase further, reaching 3 °C or more above pre-industrial levels, populations in parts of the world will likely experience levels of humid heat beyond the capacity of current coping strategies: productive economic activity, especially outdoor work, will be severely constrained. Indeed, some populations may need to take action already begun by some animal species—migration to higher latitudes.

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Conflicts of Interest

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