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Source: *Current Science*, 25 August 2011, Vol. 101, No. 4 (25 August 2011), pp. 496-503

Published by: Current Science Association

Stable URL: <https://www.jstor.org/stable/24078980>

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Workplace heat stress in the context of rising temperature in India

S. K. Dash* and T. Kjellstrom

Heat stress is an important aspect in the lives of people working under exposed conditions for long hours. It is interesting to examine the impact of global warming on the occurrence of heat stress in India. This study uses India Meteorological Department (IMD) daily temperature gridded data to investigate the changes in frequency and episodes of extreme temperature events in seven temperature homogenous regions and the country as a whole by applying the guidelines suggested by the World Meteorological Organization 'Expert Team on Climate Change Detection and Indices'. It is emphasized here that climate change may lead to significant increase of heat events and hence heat stress during the hot seasons in most parts of India. Heat stress may cause occupational health risks as well as reductions of work productivity that can have a negative impact on family income and the community economy. It is time to recognize the importance of heat stress as a public health issue and conduct more scientific studies in different parts of India to formulate guidelines for safety measures.

Keywords: Climate change, heat stress, outdoor exposure, warm spells, work capacity.

CLIMATE change has a profound impact on several sectors of the society such as energy, economy, agriculture, tourism and health. Here health includes physical, social and psychological well-being. Changes in weather and climate affect health, both directly and indirectly. More intense and frequent extreme events directly give rise to several weather-related diseases¹. On the other hand, changes in water, air and food (both quality and quantity), ecosystems, agriculture, livelihoods and infrastructure indirectly affect the hygiene and hence the health of human beings². Both direct and indirect effects on health will lead to more diseases, sufferings and hence loss of life³.

At this early stage the effects are small, but have been projected by the Intergovernmental Panel on Climate Change (IPCC)⁴ to progressively increase in all countries and regions. Climate change has (1) altered the distribution of some infectious disease vectors (medium confidence); (2) altered the seasonal distribution of some allergenic pollen species (high confidence), and (3) increased heat wave-related deaths (medium confidence)⁴. Further, IPCC has projected that there will be (a) increase in the number of people suffering from death, disease and injury from heat waves, floods, storms, fires and droughts (high confidence), and (b) continuation in the change in the range of some infectious disease vectors and the asso-

ciated cardio-respiratory morbidity and mortality (high confidence). There may also be some benefits to health, including fewer deaths from cold, although it is expected that these will be outweighed by the negative effects of rising temperatures worldwide, especially in developing countries (high confidence)⁵.

The diversity in Indian climate systems and the occurrence of four distinct seasons in most parts of the country make the climate change study in India challenging. Due to the large extension of India both along north-south and west-east, different parts of the country experience different ranges of temperature and rainfall, even during the same month or season. During the four months from June to September, the southwest summer monsoon is the predominant weather system in the country and during October to December, the northeast winter monsoon along with the western disturbances controls the weather of the country in general.

In addition, the extreme weather events in India have geographical heterogeneity. For example, cold waves, prolonged fog, snowfall, flash floods, etc. are mostly confined to the northern part; cyclonic storms, storm surges, heavy rainfall and floods are mostly observed in the coastal regions; heat waves, dry spells and droughts largely occur in Central India. In the last decade or so, heat waves have been more prevalent in states like Orissa and Andhra Pradesh on the east coast⁶, and there are incidents of very heavy rainfall in Mumbai and Balmer in the west. The study of climate change and its impact on the health sector in a diversified country like India needs

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emphasis on the regional aspects to arrive at meaningful scientific results for application. The regional and seasonal variations, on the other hand, give rise to an opportunity for epidemiological analysis of climate effects on health using comparisons between regions and seasons.

A comprehensive study⁷ of climate-related health issues in India was carried out in 2003 and is summarized as follows. There have been health and climate linkages in earlier centuries. The Famine Commission Report (published in 1898) pointed out high mortality and morbidity in India due to a wide spectrum of diseases during the drought years after 1880. Millions died due to drought and water scarcity, and the population decreased drastically. There was contact between the medical profession and India Meteorological Department (IMD) between 1870 and 1900. Most of the meteorological observatories were located in civil hospitals. During the next 70–80 years, the two professions continued independently without any contact. This study⁷ shows concern between seasonally locked disease pattern and disease dynamics such as flu, respiratory diseases in winter, dengue, malaria and water borne diseases, especially in summer. Finally it has been suggested that diseases should be monitored more efficiently and data collected regularly to study the impact of climate change. According to this important report on Indian health and climate change, this type of study is seriously handicapped due to lack of data on mortality and morbidity of different diseases in India. Air pollution adds another dimension which should be examined in detail.

In order to examine the relationship between air pollution and associated respiratory morbidity in Delhi, the monthly admissions during January 1998–December 2005 at a number of hospitals distributed across north, south, east and west Delhi were examined^{8,9}, in addition to daily admissions during January 2004–June 2005 in the respiratory unit of Safdarjung Hospital, New Delhi. Pollutants such as SO₂, NO₂, suspended particulate matter (SPM), respirable suspended particulate matter (RSPM) (from CPCB), CO and ozone (only for daily data analysis) have been considered in these studies. The meteorological parameters considered include temperature, relative humidity and wind speed from IMD. These studies suggest that the usual air pollution levels in Delhi, specifically of O₃, NO₂ and RSPM are associated with a respective increase of 24%, 13% and 3% in respiratory disease-related hospital visits. These studies have also highlighted non-uniformity in the maintenance of records and classification of diseases in the hospitals. The main limitation is that data related to hospital admissions as well as pollutant concentrations are not available on the required timescale.

Rise in global mean temperature and increase in the number of warmer years during the past several decades have been studied by a number of researchers^{10,11}. The long-term high-resolution proxy climate indicators used for the past six centuries suggest that the 1990s were hot-

ter than any year since the Middle Ages¹¹. IPCC⁴ projected more frequent and intense events in the 21st century. In India, a number of studies^{12–17} on extreme temperature events have been conducted separately using meteorological observations. Eighteen heat waves were reported in India between 1980 and 1998, the heat wave of 1998 alone affecting 10 states and causing 1300 deaths. There has been an increase in the maximum temperature during the last century over seven homogeneous regions in India⁶. The west coast showed relatively more increase in the daily maximum temperature. Heat wave-related deaths were found to be highest in Rajasthan, followed by Bihar, Uttar Pradesh, and Orissa¹⁸ during the period 1978–1999. Results also indicate¹⁷ significant increase in the frequency, persistency and spatial coverage of heat wave events in the decade 1991–2000 compared to earlier decades.

It is known that global climate change is making already hot seasons in the hot parts of the world even hotter⁴. Since 1980 many populated places (particularly urban areas) with hot climate (temperatures regularly above 35°C) have recorded 1–2°C increase in the average temperature. An additional 2–4°C increase can be expected in these places during this century, according to IPCC⁴. In urban areas with rapid development of buildings, roads and other major physical structures, the temperature increase is likely to proceed faster and to higher levels due to the ‘urban heat island effect’¹⁹.

Measuring categories of heat extremes

Climate change will lead to significant increase of heat exposure during the hot seasons in most parts of India, where heat in outdoor work and indoor work without air conditioning already creates major human heat stress. Such heat stress causes health risks and a decrease in work productivity that can have a negative impact on family income and the community economy²⁰. During March–July, spells of hot weather occasionally occur over certain parts of India. These spells are often seen to move from one region to another. A heat wave occurs when maximum temperature of a station reaches at least 40°C for the plains and at least 30°C for the Hilly regions. When normal maximum temperature of a station is less than or equal to 40°C, the heat wave departure from normal is 5°C to 6°C and severe heat wave departure from normal is 7°C or more. When normal maximum temperature of a station is more than 40°C, the corresponding departures are 4–5°C and 6°C or more respectively. When the actual maximum temperature remains at 45°C or more, irrespective of normal maximum temperature, a heat wave is declared by the IMD. In several parts of India there occur situations with high temperature and high humidity accompanied by strong solar radiation, which are unbearable and uncomfortable, but do not

come under the category of heat waves. These cases of heat stress are worth examining not only as a scientific challenge, but also for determining regulatory guidelines for the well-being of the society.

Not enough attention has been paid to past changes of temperature in India at regional levels due to unavailability of long-term homogeneous data. Today, IMD is providing good quality long series datasets of daily temperature for the research community. This study uses IMD daily temperature gridded data to investigate the changes in frequency and episodes of extreme temperature events in seven temperature homogeneous regions along with the country as a whole by applying the guidelines suggested by the World Meteorological Organization 'Expert Team on Climate Change Detection and Indices' (ETCCDI). To study high-temperature events, indices for warm days like TX90p (the number of days with daily maximum temperature above the 90th percentile of daily maximum temperatures) are said to be relevant²¹. To bring out more comprehensive analysis, we have also chosen TX95p (days above the 95th percentile) and TX99p (days above 99th percentile) to study changes in more intense warm days. Continuous episodes of 1–2 days, 3–5 days and more than 5 days of temperature events for TX90p and other indices are also studied.

Characteristics of temperature and rainfall changes in India

Figure 1 shows the anomalies in the number of warm days over All-India as well as in the seven homogeneous zones. One important observation from this figure is that the anomalies in case of the strongest warm event TX99p during the last four decades are positive, with some peak observations in the All-India category. The other two categories of warm day frequencies fluctuate relatively more from their respective mean values. The following are inferred after analysing the decadal variations. In the east coast, west coast and interior peninsula the maximum number of warm days are observed only during the last decade for all the three temperature indices. The increase in warm days is not consistent from 1969. Only during the last decade (1996–2005) do we observe such increase; it is not a part of long-term trend and therefore not significant. Statistically significant increasing trends at 10% level are identified for TX95p and TX90p in the interior peninsula only.

Figure 2 shows that the warm spell duration index (WSDI)²¹, i.e. warm spells of at least six continuous days of the type TX90p have increased to a large extent in the west coast and interior peninsula. To study warm spells we have selected those cases for which the trends in inter-annual variations are significant using Mann–Kendall statistics. As the number of WSDI events is low, we have presented the inter-decadal variations.

There is an increase in surface air temperature such as daily mean, maximum and minimum temperatures averaged over the whole country. The maximum temperature is enhanced in all the seven homogeneous zones of India, although by different magnitudes²².

On the other hand, the minimum temperature behaves irregularly with different characteristics in different zones and with a wider range of uncertainty than that of maximum temperature²³. North and South India have contributed differently to the change in the minimum surface air temperature in the last century. These may be attributed to the dominant role of the ocean in the south, and the Himalayas and aerosols (hence clouds) in the north. Heat-wave conditions are more prevalent in the east coast, whereas fogs are more prolonged in North India²³.

During the summer monsoon season, the numbers of short-spell rain events and dry spells have increased in the last half century, but long-spell rain events show decreasing trend²⁴. The short-spell rainfall events usually occur because of local convection, thunderstorms and other such meso-scale phenomena, which are not necessarily due to monsoon circulation and organized convection. The increase in the number of short rain spells may be taken as an indication of the increase in the number of intensified meso-scale conventions which are caused due to western disturbances and westward waves on the easterlies. On the other hand, long-spell rain events are usually associated with synoptic-scale or planetary-scale phenomena. It has been found that the monsoon depressions which usually contribute significantly to the monsoonal rain have decreased in number, whereas smaller systems such as LOPARS have increased in frequency²². There is also some decrease in the total rainfall during the summer monsoon months, though it is not statistically significant.

Examples of heat stress in India

Several studies have identified heat stress as an important health risk in agricultural^{25,26} and industrial sectors in India. The major industries studied so far include automotive²⁷, coal mines²⁸, ceramics and pottery^{29–31}, iron works²⁹, stone quarry²⁹ and textiles³². There are several other sectors which are yet to be explored. It is difficult to collect actual health data related to heat stress from industrial sectors in India because of the complex circumstances under which the poor workers do their jobs. There are many interwoven issues. These include the existing laws and guidelines, regulatory mechanism, relationship between the management and workers and above all, the socio-economical conditions of the workers which compel them to undertake such jobs in spite of adverse conditions. Nevertheless, studies indicate that we need to pay more attention to public health-related to heat stress in India^{29,33}.

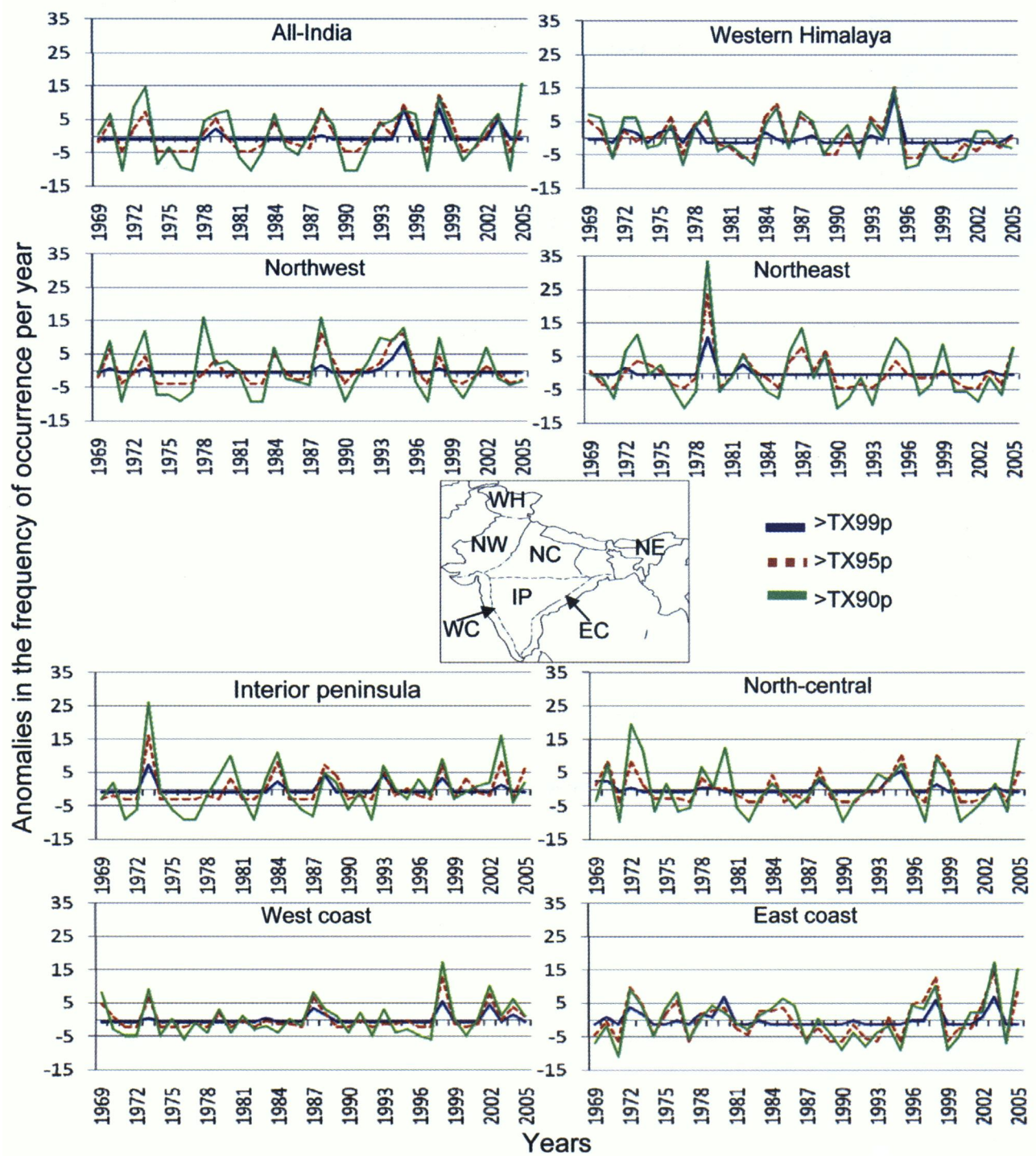


Figure 1. Anomalies in the frequency of occurrence of warm days TX99p, TX95p and TX90p over the whole of India as well as seven homogeneous regions in the period 1969–2005.

In India several agricultural labours, especially women, work for long hours exposed to high temperature and humidity conditions in the strong sun. The heat and work load of some of these people has been analysed in certain parts of India^{25,26}. Groups working in rural and semi-urban-based industries such as ceramics and pottery, and iron works in Gujarat, and stone quarry in Rajasthan are

potentially at risk of high heat exposure during peak summer months²⁹. The western states in India show increased frequency of high heat-stress events that occur regularly over a couple of weeks or so. According to the present classification, these do not come under the category of heat waves and hence go unnoticed. No regulatory guidelines are yet available in our country to determine

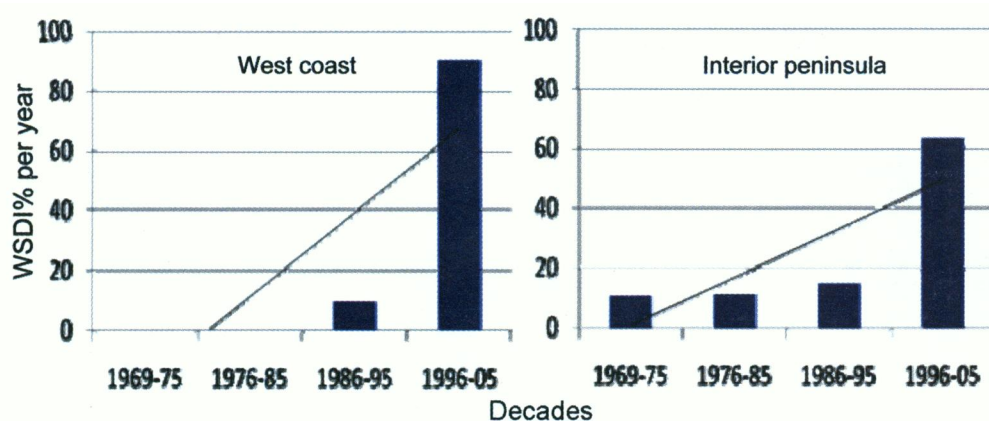


Figure 2. Decadal variations in warm spell duration index (WSDI).

the maximum limit of exposure of the workers. The available international guidelines need to be validated against our background facts.

Cases of work-related heat stress are widely prevalent in automotive and automotive parts manufacturing industries in Chennai²⁷. Nearly 400 measurements of heat stress were made over a period of four years at more than 100 locations within eight units of automotive-related industries. Such case studies emphasize the need for recognizing heat stress as an important occupational health risk in India. The risks of miners working in nine coal mines in eastern India were assessed in the context of respirable dust with free silica contents and bodily exposure of the workers²⁸. In this study, the wet-bulb globe temperature (WBGT), humidity and wind conditions were also measured. It was found that in open-cast mining, compressor and driller operators are more vulnerable. While studying the heat stress as an occupational risk, it is important to record the perceptions of the concerned people. Case studies of about 10 different industrial units in Tamil Nadu bring out the fact that due importance has not been given to heat stress as an occupational health issue³³.

Analysis of workplace heat stress

Heat exhaustion and heat stroke may be of particular importance for the occupational health of working people^{34,35}. A working person creates heat internally in the body, particularly through muscular work, which adds to the heat stress in hot environments³⁶. If cooling methods in the workplace are insufficient, the only way for a working person to reduce heat stress is to take breaks or slow down his work. This reduces the 'work capacity' (and daily work output) and economic productivity³⁷⁻⁴⁰.

Assessment of heat stress and relating that to body stress in terms of physiological and psychological stress is a complex process. For about a century efforts have been going on to formulate an index to satisfactorily

describe the heat stress. Several indices have been used by different groups. All these indices can be broadly classified into three groups, viz. rational, empirical and direct indices⁴¹. The first two groups integrate environmental and physiological variables in a sophisticated way, and hence are difficult to calculate and also impractical to use. The third group is based on basic environmental measurements and hence simple to calculate. The effective temperature (ET) index was proposed based on direct measurements of weather variables⁴². It was one of the popular indices during the 1920s and 1950s. This index was derived from a large number of laboratory experiments. Essentially ET includes the relative effects of temperature and humidity on human comforts. Nomograms⁴³ depicting the empirical description of the varying influence of humidity and air movement on thermal sensation and physiological strain over a broad range (0°–60°C) of air temperatures became standard reference material for more than 30 years. Subsequently, ET was modified⁴⁴ to include the effects of radiant heat and the modified index was called the ET including the radiant component (ETR)⁴⁴. It was shown⁴⁴ that sunlight could increase ETR by 3.6°C and a low wind of 2 m/s could reduce the temperature by 1.9°C. This happens because sunlight is the main component of atmospheric heat and wind evaporates. These two conditions, direct sunlight and wind, are physiologically important. It is well known that air movement is essential for efficient evaporation of human sweat. By not including sunlight and wind, the temperature–humidity combined limit could lead to wrong judgement of heat stress. Thus the human body working in exposed conditions may be put to unpredictable dangers. In spite of ETR being the correct measure of environmental heat, it was found unsuitable for routine use due to measurement of wind, reference to nomograms and elaborate computing. It may be noted that suitable instruments were not available then for wind measurements. The dry bulb temperature was substituted with a black-globe temperature to include the effects of sunlight

and this index was called the corrected effective temperature (CET)⁴⁵.

As part of a study on heat-related injuries during military training in the US Navy, WBGT was developed⁴⁴ and it has become the most widely used heat stress index for workplaces since then⁴⁰. The international standard for occupational heat stress uses it to quantify the need for rest breaks in different work situations⁴⁶, with the aim of keeping the core body temperature below 38°C. WBGT essentially evolved from CET. The international standard for WBGT uses formula based on measurements of three temperature variables: T_a , the air temperature in the shade measured with a dry bulb; T_g the globe temperature which is the temperature inside a black globe representing the heat radiation input; and T_{nwb} the natural wet-bulb temperature, which is measured in the actual sun and wind exposure situation, with a wet cloth over the bulb representing the impact of sweat evaporation on heat loss.

For outdoor exposure:

$$\text{WBGT} = 0.1 \times T_a + 0.2 \times T_g + 0.7 \times T_{nwb},$$

For indoor exposure:

$$\text{WBGT} = 0.3 \times T_g + 0.7 \times T_{nwb}.$$

In the absence of direct sunlight or other strongly radiating (hot or cold) surfaces in the vicinity of the human body, T_g and T_a would be similar. Hence in such cases T_g may be replaced by T_a . It may be noted that T_{nwb} is dependent on the relative humidity of the air, wind speed, solar radiation and T_a . The coefficients in WBGT have been determined empirically and this index has no physiological correlates. Nevertheless, WBGT has been recommended by several international bodies for its use in the case of exposed workers. It was also adopted as an ISO standard⁴⁶. The American Conference of Government Industrial Hygienists⁴⁷ has published the permissible heat exposure threshold limit values without adverse health effects.

The following simplified formula for calculation of WBGT has been published by the Australian Bureau of Meteorology (www.bom.gov.au).

$$\text{WBGT} = 0.567 \times T_a + 0.393 \times e + 3.94$$

Here the dry bulb temperature T_a is in °C and e is the water vapour pressure in hPa.

The vapour pressure can be calculated from the temperature and relative humidity using the equation:

$$e = \text{RH}/100 \times 6.105 \times \exp(17.27 \times T_a/(237.7 + T_a)).$$

Here, RH is the relative humidity in %.

The approximation used by the Australian Bureau of Meteorology does not take into account variations in the intensity of solar radiation or of wind speed, and assumes a moderately high radiation level in light wind conditions. Use of this approximation may lead to incorrect estimates of thermal stress. Particularly in cloudy and windy conditions, it may overestimate thermal stress. The approximation will also overestimate night-time and early morning conditions when the sun is low or below the horizon⁴⁸. The most important limitation of WBGT is that it does not adequately reflect the additional strain people experience when the evaporation of sweat is restricted by high humidity and low wind conditions. Measurement of globe temperature T_g is usually done by a thin sensor and in many occasions, it is found cumbersome. In the recent past discomfort index has been proposed to be more convenient than WBGT⁴¹.

We are collaborating with other Hothaps scientists to develop an agreement on the best formula to use in most, if not all, analyses of climate impacts on the health of working people³⁵. In the meantime the published methods are used, even if the results are not exact. Since WBGT is used as an index of heat exposure and potential heat strain during work, the average T_a for 24 h periods does not reflect the true heat stress during typical daylight hours.

Calculating heat impact on work capacity and workable days

In order to get as valid WBGT results as possible for different times during a day, we need to have access to measurements or estimates of the 24 h variation in temperature. In our WBGT calculations we have assumed the 24 h average absolute humidity (e.g. in the form of dew point, T_d). However, actual hourly measurements would be the best basis for estimating the hourly variations in WBGT. For this initial estimate, we have also calculated the daylight hour average WBGT as what most likely would reflect the heat exposure that can cause heat strain. We assumed that a representative T_a to use in the calculation of WBGT-day (WBGT-d) was the midpoint between the average 24 h T_a and the maximum T_a during the same 24 h. Using the estimated WBGT and the quantitative recommendations for hourly rest periods we could calculate the extent to which daily work patterns would be affected by heat, if workers followed these recommendations²⁰. Figure 3 shows time trends of fully workable days remaining for one of the hottest months in Delhi.

It is clear from Figure 3 that the continuous heating of the atmosphere in Delhi during the hottest months is creating heat strain that reduces work capacity. Since this is a preliminary attempt to approximately calculate WBGT and demonstrate the impact of global warming on heat stress, we have limited this study to the historical data

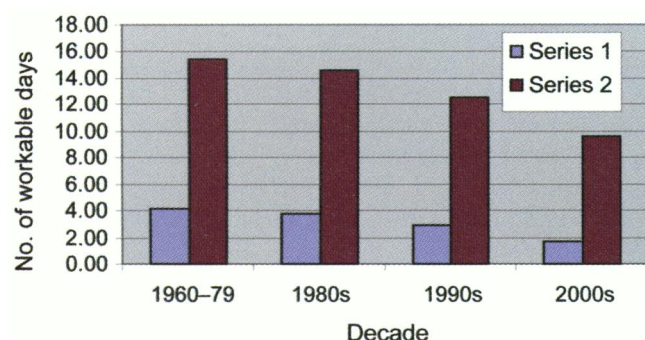


Figure 3. Fully workable days out of 30 by decade at Delhi in June. Series 1, Heavy labour; Series 2, Light factory work.

instead of predicting changes based on climate projections. It is planned to conduct more systematic study in future and develop a better WBGT formula or heat stress index.

Conclusion and recommendations

Results of this study clearly show that the work capacity of the people exposed to the warming atmosphere will reduce in the future. However, this is a preliminary study linking climate change with the working hours of people in Delhi. Such studies need to be conducted for other parts of India as well. One should use newly developed methods to quantify local heat exposures based on local climate change trends. There should be efforts to identify heat exposure situations that create heat stress health risks and reduce the ability of people to carry out daily tasks or work. Equally important is to identify the locations where such effects are already common during the hot season. Another important issue is to determine how small shifts in temperature and heat exposure due to climate change or climate variability may impact occupational health risks. In selected locations field studies on the health risks and productivity losses due to heat exposure need to be carried out. These field studies will identify methods to reduce heat exposure and effects, and they should be integrated into the local analysis of necessary adaptation to climate change. This project work needs to be carried out in close consultation with the communities participating in the studies and with local professional groups and government agencies in order to encourage broader application of the study methods and preventive interventions. It is also possible to calculate the impact on workable days based on occupation mix in the place (the city or area). This will require feeding in data about the working population of the place. For each category, the above calculations will be used to estimate the number of fully workable days lost (or remaining), and then the sum for the city to be calculated. A national-level pilot experiment involving health and climate scientists can be designed to monitor heat stress encountered

in some well-known sectors with respect to the actual heat events forecast. Duration of the project should be at least for five years so that good quality data can be generated and archived. The existing climate scenarios should be examined to find out the possible extreme weather events and the related occupational health issues on experimental basis for the future. Such a study may help in forming guidelines for appropriate remedial measures for the larger benefit of the people who are compelled to work under inhospitable, exposed conditions.

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ACKNOWLEDGEMENTS. We thank Ashu Mamgain for calculation of temperature extremes and Dr Subrat Kumar Panda for help with the preparation of the manuscript. The climate data used in this study were obtained from the India Meteorological Department.

Received 24 January 2011; revised accepted 9 June 2011