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Impact of Climate Conditions on Occupational Health and Related Economic Losses: A New Feature of Global and Urban Health in the Context of Climate Change

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Abstract

One feature of climate change is the increasing heat exposure in many workplaces where efficient cooling systems cannot be applied. Excessive heat exposure is a particular problem for working people because of the internal heat production when muscle work is carried out. The physiological basis for severe heat stroke, other clinical effects, and heat exhaustion is well known. One feature of this health effect of excessive workplace heat exposure is reduced work capacity, and new research has started to quantify this effect in the context of climate change. Current climate conditions in tropical and subtropical parts of the world are already so hot during the hot seasons that occupational health effects occur and work capacity for many working people is affected. The Hothaps-Soft database and software and ClimateCHIP.org website make it possible to rapidly produce estimates of local heat conditions and trends. The results can be mapped to depict the spatial distribution of workplace heat stress. 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 double by 2050 as global climate change progresses. By combining heat exposure data and estimates of the economic consequences, the vulnerability of many low- and middle-income countries is evident. The annual cost of reduced labor productivity at country level already in 2030 can be several percent of GDP, which means billions of US dollars even for medium-size countries. The results provide new arguments for effective climate change adaptation and mitigation policies and preventive actions in all countries.

Keywords

climate, heat, work, health, economics, climate change

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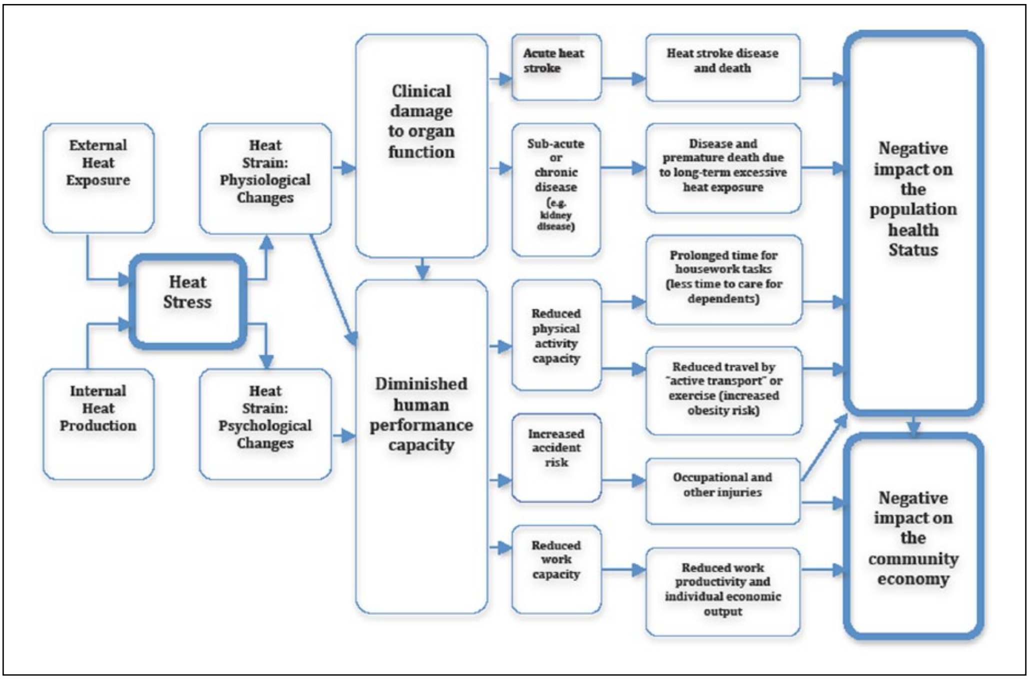

Figure 1. Schematic depiction of pathways from heat exposure to health and economic impacts.

Introduction

Of the major assessments of climate change impacts on health to date only one international[1] and one national[2] report have included analysis of how increasing *heat exposure* due to climate change will affect the *productivity and economic output* of people who have to work in the ambient hot climate. Vulnerable groups include outdoor workers and many indoor workers in factories or other workplaces without air conditioning.[3,4] These effects occur primarily during the hottest parts of the day in the hottest seasons, but in many tropical low- and middle-income countries such hot seasons continue for a large part of each year.[5] Because physical work activities add surplus heat production inside the human body to the accumulated heat load, *heat stress* becomes a particular problem for working people.[6,7] Different clinical health effects of climate conditions[8,9] are also of importance to occupational health. Heat exposure risks are a key issue for the future in urban areas.[10] The latest global assessment of climate change impacts on human health has brought the broader health and well-being issues of heat exposure to a higher visibility.[11]

If the ambient air temperature is higher than 37°C, heat transfers from the ambient air to the body and only evaporation of sweat can reduce body heat.[6,7] However, such evaporation is less effective at high humidity, and at 100% relative humidity sweating continues but it creates no body heat loss. Because of these physiological and physical conditions, working people in uncooled workplaces in tropical and subtropical areas are vulnerable to *heat strain* in the form of clinical health effects or reduced physical performance (includes reduced work capacity).[12]

The pathways from heat exposure to heat stress and to heat strain can be displayed graphically (Figure 1), and the associated physiology and health effects eventually lead to reduced population health or reduced community economic performance. As climate change causes temperatures to increase these impacts will also increase, unless efficient cooling systems are applied in workplaces in all hot locations of the world.[12]

It is sometimes suggested that acclimatization can overcome some of the effects of heat,[13] and it is true that health risks are significantly greater in unacclimatized people.[6,7] However, physiological acclimatization takes less than 2 weeks and is limited to improved sweating mechanisms.[6,7] The physical limit of evaporation of sweat from the skin in humid air remains a problem, and individual vulnerability varies. For example, in studies of South African mine workers, before acclimatization, 14% of new workers in the mines could cope with extreme heat conditions while carrying out heavy labor, and this increased to 29% after a systematic 2-week acclimatization process.[13] So 71% of workers were still not able to cope with the heat conditions after physiological acclimatization. Behavioral acclimatization via "self-pacing" of work is of great importance, but it means taking more rest and working slower, which reduces productivity.[12] This article will present examples of the estimates of lost economic output due to heat, focusing on countries in Asia.

Methods, Heat Analysis

The heat data are presented as indoor values of WBGT (Wet Bulb Globe Temperature), a common heat exposure index that combines temperature, humidity, wind speed, and heat radiation into one value.[6,7] Based on weather station data from around the world (and available for free from US NOAA) time trends were calculated with published methods.[14] These trends can be presented as trends of monthly or annual averages, or as trends of number of days above a specific threshold. One example is given in this article, and data from thousands of other weather stations are available in a freely available database and software ("Hothaps-Soft"; see www.ClimateCHIP.org).

In order to make maps of the heat situation in different parts of the world, data in 60 000 grid cells (0.5° × 0.5°) from CRU (Climate Research Unit at University of East Anglia, UK) were used to calculate WBGT for different months and years. Future model data were also included, as highlighted in an analysis for South-East Asia.[15] Heat maps for India were produced indicating what time percentage of typical daylight work hours can be maintained at different heat exposure levels, using the international standard[16] as the basis for exposure–effect relationships. The reduction of hourly active work time is expressed as "loss of work capacity due to heat."

Methods, Economic Impact Analysis

The economic impacts were presented in the detailed report Climate Vulnerability Monitor 2012.[1] The loss of work capacity due to workplace heat in 2010 and 2030 in 21 geographic regions around the world has been published.[17] The national loss estimates used the proportion of the work force in jobs with different physical demands and different heat exposure levels, based on a World Bank model.[17] In the Climate Vulnerability report,[1] the regional data were converted to national data within each region, using population estimates and further assessments of workforce distribution. Eventually, the lost work hours data were converted to cumulated annual losses. It was assumed that these losses affected annual GDP to a similar degree. The losses, as percent of daylight work hours, were multiplied with the estimated GDP for 2011 and 2030, based on international projections of GDP (see: http://www.pwc.com/en_GX/gx/world-2050/assets/pwc-world-in-2050-report-january-2013.pdf), and the economic value of the lost work capacity (reduced labor productivity) was calculated. Examples from this analysis are given in the tables.

Ambient Heat Exposures in Vulnerable Countries

To get improved evidence of local heat exposures on working people and a basis for assessing impacts of ongoing and future climate change, the global Hothaps program was developed.[18] The program uses WBGT as the preferred heat stress index for workplace conditions.[6,7,14]

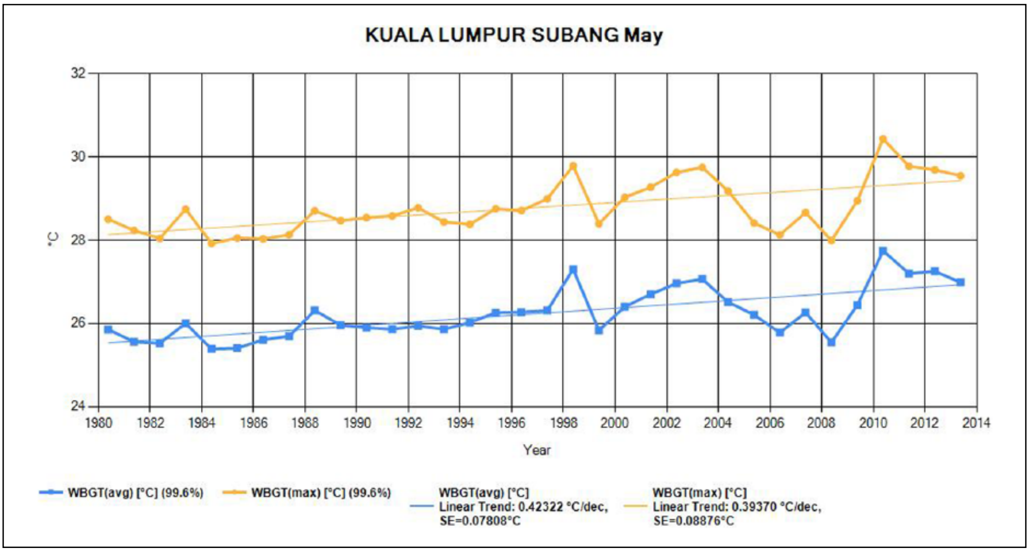

Figure 2. Time trends of WBGTmax (afternoon values) and WBGT average (based on 24-hour average temperature and humidity) indoors or in full shade as averages of daily values for the month of May in Kuala Lumpur, Malaysia (Subang airport weather station).
Using the "threshold" analysis in Hothaps-Soft, it can be seen that the number of days per year that WBGTmax exceeds 29°C has gone from a few days in the 1980s to more than 100 days in recent years.

As an example of the time trend outputs from the software and database "Hothaps-Soft," Figure 2 shows the situation for Kuala Lumpur in the month of May. These are the indoor (in-shade) WBGT levels during afternoons, and outdoor levels in the sun are usually a few degrees higher.[15] Thus, the WBGT levels produced via Hothaps-Soft are lower than the levels people in certain jobs would experience, if they work outdoors in the afternoons.

Heat Impact on Work Capacity and Labor Productivity

The data on current or future heat levels in workplaces can be assessed in terms of lost work capacity using exposure–response relationships from the few epidemiological studies available,[13,19] or by using the recommended rest-to-work ratios in the international standard for workplace heat exposure.[16] As mentioned earlier, the WBGT data in Figure 2 and in the following tables are all values in full shade or indoors, and these values would be representative for many factory and workshop situations where air conditioning is not available. Figure 3 indicates the estimated levels of work capacity loss in India based on 0.5° × 0.5° (approximately 50 × 50 km) grid cell climate data for the decade around 2005. The 4 maps show the situation during the cool season (January), the dry hot season (April), the wet hot monsoon season (July), and the post–monsoon season (October). In the 2 hottest seasons large parts of India are so hot that afternoon work becomes almost impossible according to this international standard.

The local populations are clearly "behaviorally adapted" to these heat levels, and the stories of how outdoor workers cope[3] indicate, for instance, that construction workers in India rest during the whole afternoons in the hot seasons. As climate change slowly makes the hottest days hotter, and there will be longer periods of excessively hot days, the impact on hourly labor productivity due to the increasing need for rest is likely to become a significant problem for many countries and communities.

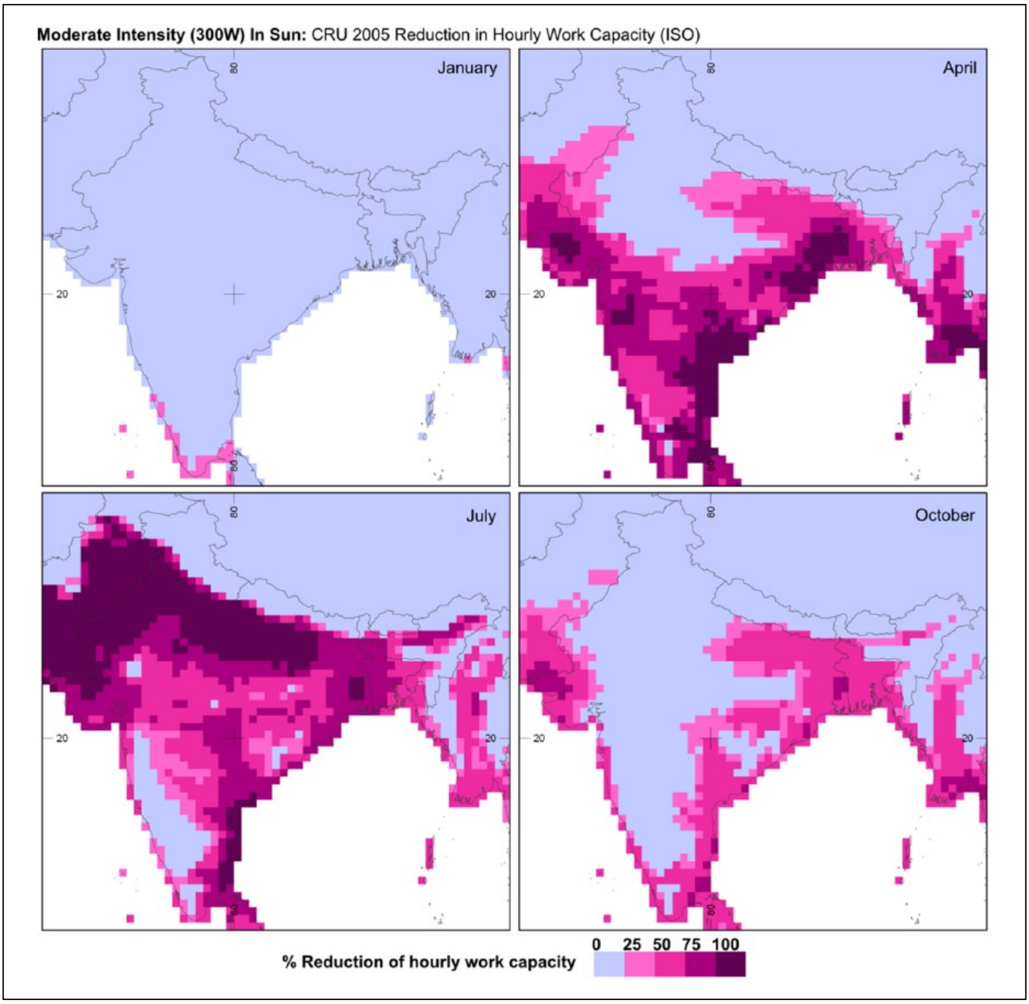

Figure 3. Reduction in hourly work capacity (daylight hours) for 4 seasons of a year, based on the ISO standard[16] for moderate work intensity in the sun in the decade around 2005.

The Additional Heating From UHI Effect in Urban Areas

The heat impact assessments in the maps (Figure 3) are based on the average climate data for grid cells covering approximately 2500 km^2, and can be assumed to mainly represent the less urbanized areas of the grid cell. It is well known that urban areas during hot periods have higher average ambient temperatures than the surrounding rural areas. This is called the "urban heat island" (UHI) effect,[20] and it is due to the absorption of heat from the daily solar radiation into concrete, asphalt, and other solid materials common in built-up areas. The greatest effect on air temperature is at night when the stored heat is released back to the ambient air, but air temperatures during sunny days are also higher in the daytime.

With the data and software in Hothaps-Soft one can compare the climate data and estimated WBGT levels at central city weather stations with the data from airports (usually in less urbanized areas). For example, monthly Tmax data for Hanoi urban locations are higher than for surrounding rural locations. The time trends can also be seen to be more pronounced. In Bangkok at the

Metropolis (city center) and Don Muang (airport) locations the WBGT trends are 0.29°C/decade and 0.17°C/decade, respectively. Thus, the heating trend goes faster in the center of the city.

The application of air conditioning in urban workplaces as an "adaptation" to climate change is fraught with concern about the sustainability of such a "cooling future."[21] On a large urban scale, the increased use of air conditioning creates additional heating of local outdoor air and an increase of electricity demand. This is already causing major stress on the electricity infrastructure, and the additional energy needed for a city the size of Bangkok for each 1°C increase of average ambient temperature can be as much as 2000 MW.[21] There is a great need for renewable energy solutions to cooling systems for both workplace and residential buildings in tropical and subtropical areas of the world.

Links Between Workplace Heat Exposure and Economic Output

The loss of work capacity due to heat exposure was calculated for 21 global regions at "baseline" (1960-1989) and future periods (2030 and 2050).[17] The methods include assessments of the likely impact of socioeconomic changes and changes of workforce distribution into agriculture, industry, and services. The work capacity loss in 2050 in the South Asia and South-East Asia regions were 11.5% and 18.2% of annual workdays, respectively. Taking the assumed impact of socioeconomic changes into account, the losses were reduced to 4.4% and 2.0%, respectively.[17] These estimates used rather limited climate and population data for each region. Further updated analysis with more detailed data for each grid cell is now emerging. As an example, for South-East Asia[15] the new estimates (taking workforce changes into account) indicate work capacity losses increasing from 17% to 29% (of daylight work hours) from 1975 to 2050 for outdoor workers doing heavy labor. The corresponding figures for indoor workers doing heavy labor are 3% to 8%, and for outdoor workers doing moderate labor the estimates go from 7% to 15%.[15] The outdoors data were assumed to have 3°C hotter WBGT values than the calculated indoors data (this is tentative, as the difference will vary by month and location).

The following tables show a selection of heat and economics data: the numbers of days with high WBGT and the time trends assembled from weather station data at capital cities as well as annual economic loss estimates from the Climate Vulnerability Monitor 2012.[1]

The Climate Vulnerable Forum (CVF) is an organization of 20 low- and middle-income countries (Table 1) that consider that they are threatened by climate change but have contributed very little to its causes (see: http://www.thecvf.org/). This Forum has 24 observer countries, and the tables give an indication of the different heat conditions of some of the CVF members and observer countries, as well as some other countries in the Asia and Pacific region. More than half the year experiencing "serious heat" levels is common in the CVF member countries (Table 1), but occurs in only one (Qatar) of the higher income countries (Table 1). The non-CVF low- and middle-income countries (Table 2) all have more than 220 days of "serious heat" each year.

The 30-year time trends of WBGTmax in the capital cities varies from small negative values up to 0.66°C/decade (in Canberra, Australia), but the heat impact change is greater if the location starts from a high heat level, like most of the CVF member countries and the other low- and middle-income countries (Tables 1 and 2).

Based on this type of calculations, economic loss estimates were presented in the Climate Vulnerability Monitor 2012.[1] The percentage workdays loss per year was applied to the GNP or GDP estimates for each country (Tables 1 and 2). Table 3 summarizes the ranges and the upper extremes of economic impacts of heat-related loss of work capacity in different countries. It is clear that the high-income observer countries in the Climate Vulnerable Forum have limited loss or even improved GDP as a result of climate change in the short period presented, while the losses in the low- and middle-income countries are much higher—up to approximately 6% of annual GDP (Table 3).

Table 1. Heat Exposure and Economic Data for Member States and Observers in the Climate Vulnerable Forum[a,b,c].

Variable Code	Variable Content and Unit
A	GNP per capita in 2011, US$ PPP (2005$)
B	Cost of labor productivity loss due to excessive heat, % of GDP in 2010
C	Cost of labor productivity loss due to excessive heat, % of GDP in 2030
D	Cost of labor productivity loss due to excessive heat, millions of US$ PPP in 2030
E	Cost of all climate change (CC) impacts, % of GDP in 2030
F	The annual trend of WBGTmax (afternoon values, in shade or indoors), 1984-2013, °C/decade change, at key weather station at the capital city (usually the main airport)
G	The annual trend of number of days with WBGTmax (afternoon values, in shade or indoors) higher than 26°C, 1984-2013; change per decade at this weather station
H	Number of days/year when WBGTmax is >26°C in typical year (recent 5-year average) at this weather station

Climate Vulnerable Forum Member States

Variable code	A	B	C	D	E	F	G	H
Country	GNP/cap 2011	Heat Loss 2010, % of GDP	Heat Loss 2030, % of GDP	Heat Loss 2030, millions $US	Total CC Loss 2030, % of GDP	WBGTmax trend, °C/ decade	Serious Heat Days, Decade Trend	Serious Heat Days/Year
Bangladesh	1529	1.5	3.0	30 000	6.8	0.09	NA	NA
Costa Rica	10497	2.3	4.5	9000	6.3	0.1	NA	3
Ethiopia	971	1.3	2.4	6000	3.7	0.24	NA	0
Ghana	1584	3.2	6.5	15 000	8.9	0.16	12	280
Maldives	5276	3.0	5.6	550	15.9	0.09	NA	360
Philippines	3478	2.9	5.9	85 000	7.1	−0.12	19	320
Saint Lucia	8273	1.6	3.0	250	6.6	0.15	16	280
Tanzania	1328	1.3	2.2	4000	4.8	0.16	26	260
Tuvalu	NA	5.5	3.6	5	23.1	0.19	0	360
Vanuatu	3950	1.9	3.4	150	44.8	0.34	34	230
Vietnam	2805	2.9	5.7	85 000	10.7	0.02	0	170
Other countries in the Asia-Pacific region								
Cambodia	1848	3.0	5.7	9250	10.30	0.09	6	320
Fiji	4145	1.8	3.8	600	11.10	0.35	30	220
Laos	2242	3.0	5.8	4750	7.10	0.22	17	260
Malaysia	13 685	2.8	5.9	95 000	7.30	0.35	4	362
Myanmar	1535	3.0	5.5	15 000	12.90	0.1	26	340
PNG	2271	2.0	3.8	2250	12.10	NA	48	280
Samoa	3931	1.9	3.5	150	9.90	0.29	7.7	320
Sri Lanka	4943	3.0	5.9	25 000	7.40	0.15	NA	320

[a]NA, sufficient data not available in the data sources used.
[b]Source: *Variables A-E:* DARA (2012).[1] *Variables F-H:* Local weather station data at capital city location, usually airport (NOAA/GSOD), or CRU data for the grid cell with this weather station (see: Hothaps-Soft in ClimateCHIP.org).
[c]Other forum member states: Afghanistan, Barbados, Bhutan, Kenya, Kiribati, Madagascar, Nepal, Rwanda, and Timor-Leste.

The estimated annual losses, expressed as $US PPP, are already in 2010 up to 55 billion (India) and in 2030 up to 450 billion (India and China; Table 3). Many of the low- and middle-income countries listed in Tables 1 and 2 have estimated annual losses at multibillion dollar levels. These are tentative estimates, but they indicate the importance of further analysis of this climate impact in many countries struggling to reduce poverty and improve socioeconomic conditions.

Need for Prevention Policies and Actions

The size of these potential economic losses (billions of dollars in a year) indicates an urgent need to update and validate these estimates for each country based on the latest climate modeling

Table 2. Heat Exposure and Economic Data for 24 Observer Countries in Climate Vulnerable Forum[a].

Variable Code	A	B	C	D	E	F	G	H
Country	GNP/cap 2011	Heat Loss 2010, % of GDP	Heat Loss 2030, % of GDP	Heat Loss 2030, millions $US	Total CC Loss 2030, % of GDP	WBGTmax Trend, °C/decade	Serious Heat Days, Decade Trend	Serious Heat Days/Year
Higher income observer countries								
Australia	34 431	0.0	0.0	100	0.80	0.66	2.3	6
Denmark	34 347	0.0	0.0	0	−0.30	0.45	0	0
France	30 462	0.0	0.0	0	0.90	0.35	0.5	2
Germany	34 854	0.0	0.0	0	NA	0.48	NA	NA
Japan	32 295	0.0	0.0	1000	0.10	0.23	2.6	50
Netherlands	36 402	0.0	0.0	0	−0.10	0.31	0	0
New Zealand	23 737	0.0	0.0	15	0.60	0.17	0	0
Norway	47 557	−0.1	−0.2	−650	−1.70	0.53	0	0
Qatar	107 721	0.0	0.1	450	0.30	0.3	5.4	195
Russia	14 561	−0.1	−0.2	−15 000	0.80	0.46	1.4	4
South Korea	28 230	0.0	0.0	1000	0.40	−0.06	−1	22
Spain	26 508	0.0	0.0	0	1.00	0.04	−4.8	3
Sweden	35 837	−0.1	−0.2	−950	−1.40	0.49	0	0
United Kingdom	33 296	0.0	0.0	0	−0.30	0.23	0	0
United States	43 017	0.1	0.2	50 000	0.50	0.14	0.4	44
Low- and middle-income observer countries								
China	7476	0.4	0.8	450 000	1.30	0.24	3	75
DR Congo	3066	2.5	4.6	3250	8.50	−0.02	19	200
India	3468	1.5	3.2	450 000	4.30	0.45	10	195
Indonesia	3716	2.9	6.0	250000	7.00	0.06	NA	NA
Mexico	13 245	2.3	4.4	250 000	6.10	0.28	0	0
Nigeria	2069	3.3	6.4	75 000	7.60	0.21	NA	NA
Pakistan	2550	1.5	2.8	50 000	4.40	0.2	8.5	140
South Africa	9469	0.2	0.5	7250	1.90	0.24	0	0
Thailand	7694	2.9	6.0	150 000	7.20	0.39	7.8	335

[a]For details of the variables and the data sources, see Table 1. Negative economic losses imply reduced labor productivity effects during cold seasons.

Table 3. Economic Impact of Heat-Related Loss of Labor Productivity in the Groups of Countries Presented[a].

	Number of Countries	Heat Loss, $US millions, PPP		% of GDP	
		2010	2030	2010	2030
CVF members, all low or middle income	20	Up to 10 000 (Philippines)	Up to 85 000 (Philippines)	1.1 to 5.5	2.0 to 6.5
CVF observers, low/middle income	9	Up to 55 000 (India)	Up to 450 000 (China and India)	0.2 to 3.3	0.8 to 6.4
CVF observers, high income	15	Up to 15 000 (USA)	Up to 50 000 (USA)	−0.1 to 0.1	−0.2 to 0.2
Other countries, South-East Asia, low/middle income	8	Up to 10 000 (Malaysia)	Up to 95 000 (Malaysia)	1.8 to 3.0	3.5 to 5.9
Other countries, South-East Asia, high income (Brunei and Singapore)	2	Up to 25 (Singapore)	Up to 200 (Singapore)	0 to 0.005	0 to 0.02

[a]Data from the Climate Vulnerability Monitor (2012).[1]

results and local socioeconomic characteristics. This will help identify the implications for local prevention via adaptation or mitigation policies and actions. The need for cooling systems, particularly in indoor workplaces, has already been highlighted,[21] but many jobs cannot be cooled and reduced work during the hottest part of the days will be required. This is included in occupational health advisories available at national levels and is the basis for the international standard.[16] The changed work hour distributions can be seen as a part of "climate change adaptation," but the likely loss of economic output needs to be considered as an important "side-effect" of this type of adaptation.

Prevention also includes the very basic need for sufficient and easy access to drinking water in all hot workplaces, to replace water loss from sweating. The workers and supervisors at hot workplaces also need to learn about symptoms of severe heat strain and emergency actions to protect workers at early stages of heat stroke. These are issues that the local health sector needs to attend to, and a key task is to communicate risks and prevention options to the supervisors and managers of both large and small workplaces. The health sector also needs to be involved in local analysis of heat exposures, health impacts, and labor productivity impacts, in order to be able to provide health expertise and evidence for intersectoral policies and actions. Local-level descriptions of climate conditions and climate change, as well as information on prevention options, can be seen on the website: www.ClimateCHIP.org.

The new analysis and related studies based on Hothaps principles can produce evidence of the limitations of prevention achieved via "adaptation" methods and the "side-effects." Thus, in certain localities, and maybe for whole countries, these limitations will indicate that the most effective way to protect health and economic progress will be via global mitigation of climate change.

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