

# The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies

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The 'high occupational temperature health and productivity suppression' programme (Hothaps) is a multi-centre health research and prevention programme aimed at quantifying the extent to which working people are affected by, or adapt to, heat exposure while working, and how global heating during climate change may increase such effects. The programme will produce essential new evidence for local, national and global assessment of negative impacts of climate change that have largely been overlooked. It will also identify and evaluate preventive interventions in different social and economic settings.

Hothaps includes studies in any part of the world where hourly heat exposure exceeds physiological stress limits that may affect workers. This usually happens at temperatures above 25°C, depending on humidity, wind movement and heat radiation. Working people in low and middle-income tropical countries are particularly vulnerable, because many of them are involved in heavy physical work, either outdoors in strong sunlight or indoors without effective cooling. If high work intensity is maintained in workplaces with high heat exposure, serious health effects can occur, including heat stroke and death.

Depending on the type of occupation, the required work intensity, and the level of heat stress, working people have to slow down their work in order to reduce internal body heat production and the risk of heat stroke. Thus, unless preventive interventions are used to reduce the heat stress on workers, their individual health and productivity will be affected and economic output per work hour will be reduced. Heat also influences other daily physical activities, unrelated to work, in all age groups. Poorer people without access to household or workplace cooling devices are most likely to be affected.

The Hothaps programme includes a pilot study, heat monitoring of selected workplaces, qualitative studies of perceived heat impacts and preventative interventions, quantitative studies of impacts on health and productivity, and assessments of local impacts of climate change taking into account different applications of preventative interventions.

Fundraising for the global programme is in progress and has enabled local field studies to start in 2009. Local funding support is also of great value and is being sought by several interested scientific partners. The Hothaps team welcomes independent use of the study protocols, but would be grateful for information about any planned, ongoing or completed studies of this type. Coordinated implementation of the protocols in multi-centre studies is also welcome. Eventually, the results of the Hothaps field studies will be used in global assessments of climate change-induced heat exposure increase in workplaces and its impacts on occupational health and productivity. These results will also be of value for the next assessment by the Intergovernmental Panel on Climate Change (IPCC) in 2013.

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## Background: key issues concerning climate change and health

Global climate change is making already hot seasons in hot parts of the world even hotter (1). Since 1980, many populated places (particularly cities) with hot climates (temperatures regularly above 35°C) have already recorded 1–2°C increases in average temperature (2). Additional 2–4°C increases can be expected in these places during this century according to the Intergovernmental Panel on Climate Change (IPCC) (1). 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’ (3, 4).

A range of health impacts related to climate and climate change have been identified (1, 5, 6). These include heat exhaustion, heat stroke, kidney disease, effects of additional air pollution, injuries and mental stress from extreme weather events, vector-borne diseases, diarrhoea and malnutrition. Many of these can create higher health risks among working people.

Heat exhaustion and heat stroke are of particular importance for occupational health. A working person creates heat internally in the body (particularly through muscular work), which adds to the heat stress in hot environments (7). 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 their work. This reduces ‘work capacity’ (and daily work output) and economic productivity (8–10).

Even daily physical activities in the household can cause heat stress and may need to be reduced, resulting in less ability to carry out tasks on hot days. Travelling to and from work is another daily source of heat exposure for many people (7). Adults carrying out heavy labour are exposed (10), while children and the elderly are likely to be particularly sensitive to over-heating.

These non-fatal impacts on people exposed to heat are the focus of the ‘Hothaps (high occupational temperature health and productivity suppression)’ research and prevention programme introduced in this article.

## Background: key issues concerning workplace heat, health and productivity

The Hothaps research programme contributes to the ongoing gathering of evidence on climate change and health. The idea for these studies emerged at an IPCC meeting in Delhi in December 1998 and was later presented at a conference (9). Numerous review reports on climate change and health (1, 5, 6, 11, 12) have highlighted the increasing human health risks due to heat waves, extreme weather conditions, increased air pollution, lack of access to safe water and food, spread of disease vectors and human displacement due to flooding,

drought or sea-level rise. Analysis of the non-fatal impacts of direct heat exposure on people, particularly when they work in physically demanding jobs, has so far been very limited. The IPCC report (1) mentions this issue only briefly.

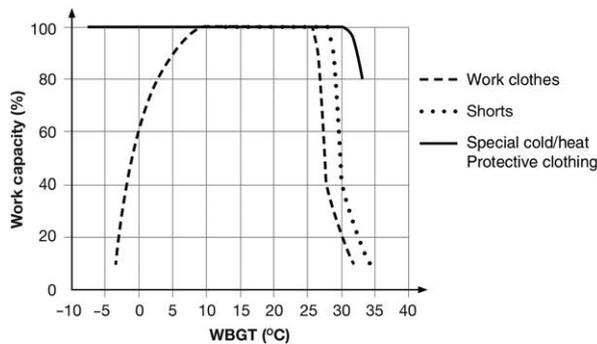
The physiological basis for the direct effects of heat on humans and their work capacity is well understood (e.g. 7, 10, 13). The core body temperature of all human beings needs to be close to 37°C. Temperatures a few degrees higher than this can cause malfunction of body systems (7). The human body has physiological heat control mechanisms that can maintain the core body temperature even when the external air temperature is greater than 37°C. These mechanisms rely heavily on sweating, which becomes less efficient as the relative humidity of the air increases.

High heat exposure initially causes heat strain, which is subjectively perceived as unpleasant or dangerous, and this can progress into heat exhaustion (fatigue), heat stroke (7, 10) and even death (14, 15, 16). The main determinants of heat exhaustion are increases of body temperature and heart rate, as well as dehydration due to sweating without liquid replacement (7).

The climate variables used to define heat exposure and ‘microclimate’ are primarily temperature, humidity, direct heat radiation, diffuse heat radiation and wind speed at the work place (10). A combined measure of these is the Wet Bulb Globe Temperature (WBGT, recorded as °C), the indicator used in the International Standards Organization occupational exposure standard (17). Where WBGT measurements are not available, it is possible to model these approximately using data from weather stations (18; Lemke and Kjellstrom, to be published).

A natural reaction of a working person to heat is to reduce physical activity, which reduces the body’s internal heat production. This preventive reaction leads to reduced work capacity during exposure to heat (13, 16). Thus, the impact of increasing heat exposure on work capacity is a result of the natural preventive actions of working people to reduce heat stroke risk by slowing down work (‘autonomous adaptation to climate change’, 19). The degree of reduced work capacity in relation to heat exposure (as measured by the heat index WBGT) is shown schematically in Fig. 1, which also highlights the influence of clothing on the heat impact.

At WBGT values over 25°C, work capacity starts to decrease, and at WBGT values over 40°C it is very difficult to carry out any physical activity at all. Depending on air humidity, wind speed and heat radiation (e.g. from the sun), a WBGT range of 25–40°C occurs at air temperatures in the range 30–45°C. Such temperatures are common during the hot season in tropical and some sub-tropical countries. Many work situations are such that air conditioning is not feasible



**Fig. 1.** Conceptual distribution of work capacity in relation to heat exposure (WBGT) and clothing based on ergonomic practice (7) and the international standard for work in hot environments (17). (Shorts or other very light clothing are not expected to be worn for work at WBGT below 15°C; common work clothes provide protection down to below 10°C, while they increase heat stress somewhat at WBGT above 25°C; at extreme hot and cold exposures special clothing can protect work capacity).

(work outdoors or in very large open indoor spaces), and fans are not sufficient when the heat exposure is very high (fans even increase the heat exposure when the air temperature exceeds skin temperature; 10).

The Hothaps team is developing a Population Heat Exposure Profile (PHEP), an analysis tool that presents the current heat situation and time trends for relevant climate and heat exposure variables for each month of the year (Kjellstrom and Lemke, to be published). Based on daily climate data from 13,000 weather stations around the world, acquired from websites at the US National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA), the PHEPs present seasonal and intra-daily (hourly) variations in heat exposure. These can be used to estimate the associated health and productivity impacts. Fig. 2 demonstrates examples of data from Delhi, India, in August 1999 (August being one of the hottest months in Northern India).

### Hothaps (high occupational temperature health and productivity suppression) programme overview (towards IPCC 2013)

#### *Achievements to date: problem definition and preliminary global assessments*

The Hothaps team has identified this problem associated with climate change and raised awareness of this effect of climate change via annual conference presentations, published journal articles (16), book chapters (20, 21) and monographs (2, 22), in order to alert interested people to the potential occupational health problems that increased heat exposure might cause. The physiological and ergonomic mechanisms behind the effects of heat on

humans have been reviewed (23, 24). A first global assessment of the impact of workplace heat on productivity has been carried out (25). Plans for future Hothaps work have been developed and fundraising for this research has started.

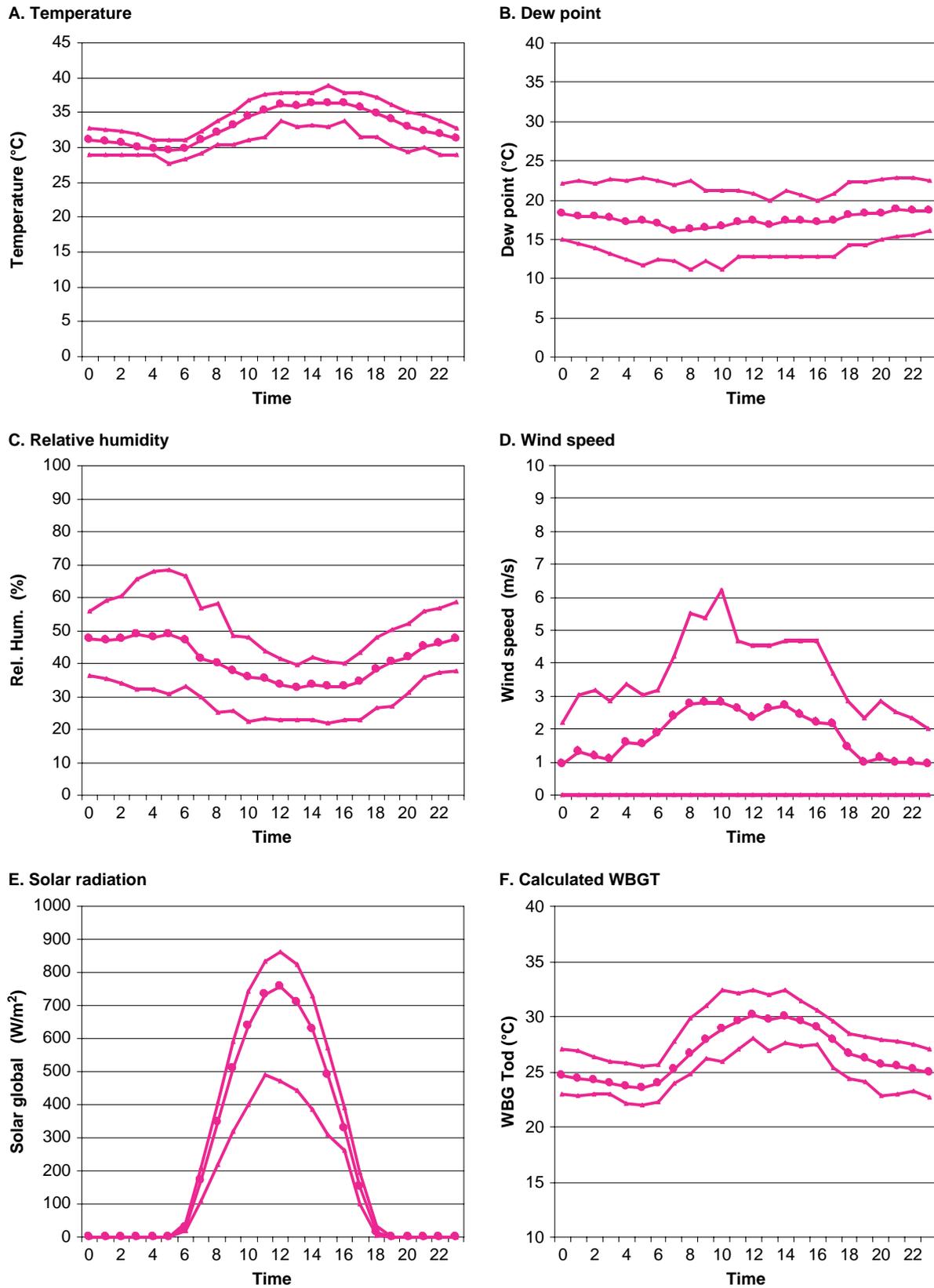
#### *Current activities: methodological development, model design and study planning*

Specific methods for improving heat exposure estimation (for instance the calculation of WBGT from weather station data) and the PHEP is under development and will be tested and promoted as a new tool for improved human exposure assessment. Modelling of heat exposure and the related effects based on existing physiological models is providing first stage estimates of how the increasing human heat exposure may impact on different population groups in different parts of the world. Preliminary global assessments of heat-related productivity loss or burden of disease are indicating how large the Hothaps effect may become with climate change, and its geographical distribution.

The different elements of health impact analysis (for instance burden of disease elements) are currently reviewed by the Hothaps team and new models for calculating impacts will be developed and tested. Besides WBGT, other relevant heat stress indices will also be reviewed. Human variability in the heat–health relationships will be quantified by using statistical distribution concepts and incorporated into statistical models for impact analysis. The need for preventive interventions in occupational health is also under study, including assessments of the prevention provided by international guidelines and standards. The plan and protocols for local Hothaps field studies in different parts of the world are being tested and funding for research is being sought. Four pilot studies are currently being carried out in India, Thailand and Costa Rica.

#### *Future plans: field studies to assess local conditions in different countries, 2009–2011*

In as many places as possible, Hothaps field studies will be carried out in as many places as possible, generating new evidence about health and productivity effects, local heat warning systems and preventive occupational health programmes. The results will be pooled to produce new quantitative exposure–response relationships for effects of excessive heat exposure on occupational health and productivity. Heat exposure descriptions based on local PHEPs will, together with climate change models, be developed into projected future occupational heat exposure scenarios and combined with exposure–response relationships to produce local or national climate change occupational health and productivity impact assessments.



*Fig. 2.* Examples of hourly data in a Population Heat Exposure Profile for Delhi, August 1999. Includes shade temperature, dew point, relative humidity, wind speed, solar radiation (global) and WBGT outdoors (middle curve, averages; bottom and top curves, 5th and 95th percentiles of values for each hour on individual days during the month).

### **Future plans: detailed quantitative global assessments and preventive strategies, 2011–2012**

Global occupational heat stress maps will be produced based on PHEPs and climate change predictions. The results of Hothaps field studies and heat exposure mapping will be used to make global health and productivity impact assessments. New preventive interventions ('adaptation' approaches) for occupational health will be devised. The results of the Hothaps global occupational health impact analysis will be delivered to the IPCC.

### **Aims and objectives for the Hothaps (high occupational temperature health and productivity suppression) field studies**

#### **Overall aims**

The Hothaps international research programme aims at characterising and quantifying the effects of heat on occupational health and work capacity in different parts of the world, taking future climate change into account. It also aims at building knowledge about and finding effective preventive interventions (adaptation) against increasing occupational heat stress due to global climate change.

#### **Specific objectives**

- 1) Develop improved methods to quantify heat exposure relevant to human health and performance (work capacity), based on an established heat stress index and routine weather station data.
- 2) Identify heat exposure situations that create health risks and reduce the ability of people to carry out daily tasks or work, and identify the locations in the world where such effects are already common during the hot season.
- 3) Identify occupations in countries in different climate zones that are particularly vulnerable to heat-induced health risks and work capacity suppression, due to the work being outdoors during the hot season or indoors in places where heat reducing interventions are not in place.
- 4) Measure the impact of heat exposure on current work output and daily life activities, and, if possible, on relevant physiological and psychological indices as well as clinical disease.
- 5) Determine in selected countries how small shifts in temperature and heat exposure due to climate change or climate variability may impact on occupational health risks and work capacity in different occupations and assess how this compares to other 'dis-abilities' caused by disease or injury.
- 6) Model the empirical relationship between recorded weather variables and observed workplace heat

stress, to enable estimation of occupational heat stress in countries where field studies are yet to be carried out, and thereby to evaluate the global impact of the Hothaps effect.

- 7) Provide input into analyses of climate change impact on population health, worker productivity and economic conditions at local, national and global level.
- 8) Identify preventive measures ('adaptation') that can be taken to reduce the current and future climate impacts on occupational health and quantify their effectiveness in different countries and settings.

### **Overview of field study components**

The Hothaps field study programme contains five components briefly described below (detailed protocols can be acquired from the Hothaps team). The proposed methods will need to be adapted to local conditions, while harmonisation of exposure and effect variables is important for combined analysis of the global Hothaps impact. Ideally, a Hothaps pilot study should be completed before carrying out the subsequent field studies. However, the components can be carried out separately or in combination. The field studies should ideally be carried out using participatory approaches with key target groups in order to ensure that the studies take their concerns into account.

#### **Pilot study for Hothaps field studies**

The pilot study will describe the general heat exposure situation for people in the country, make initial comments on how people cope with heat, and tentatively identify occupational and community groups that might already be affected by heat and therefore particularly vulnerable to increasing heat caused by future climate change. The first stage would be a literature review of any local information on heat problems at work, warning systems and preventive interventions (the review of published and unpublished information should ideally go back to the 1950s as in some countries studies were carried out this long ago). Existing workplace heat exposure data can be complemented by climate measurements in selected workplaces to compare with published data or weather station data.

A list of broad questions will be used to collect information from key informants about the heat exposure situation and impacts on health and work capacity in a specific location (a suggested questionnaire will be provided by the Hothaps team). The key informants could include occupational health practitioners, public health professionals, social scientists, community organisation representatives and well-informed people from different economic sectors.

The questionnaire study will identify common observations of the way people describe the impacts of heat on

their health, and will collect ‘anecdotal’ evidence about how work and daily life are affected by heat and what measures people take to reduce the impact of heat. These qualitative data can be used to generate hypotheses about specific factors that influence heat stress, to identify potential preventive interventions and to inform quantitative studies. The information about the types of heat protection interventions used in the study location can be combined with the literature review information to propose heat warning systems and other preventive interventions.

The pilot study report is an important first step towards the other components of the programme and related fundraising activity. The report should ideally include a proposed timetable and budget for each of the other programme components the research group is considering.

### ***Basic local heat monitoring and occupational exposure assessment***

The basic contributors to human heat exposure are air temperature and humidity, wind speed and heat radiation (which in outdoor locations is usually from solar radiation). Thousands of weather stations around the world measure at least the first three of these variables. However, spatial and temporal variations at local level are great, and to estimate human heat exposure accurately, local measurements at workplaces are needed.

The preferred heat stress index is WBGT. There are two components of the WBGT that are not measured routinely at weather stations, the natural wet bulb temperature and the globe temperature. If specialised equipment can be acquired, it is possible to carry out measurement of all the WBGT components. However, without such equipment, measurement of air temperature and humidity is a good starting point for calculating WBGT using the methods used in the PHEPs with assumptions about wind speed and heat radiation exposure.

### ***Exploratory qualitative studies of occupational heat impacts and preventive approaches***

In this component groups of heat exposed workers are asked to answer questions in a questionnaire similar to the one used in the pilot-study with key informants. A participatory approach can be used to adapt the questionnaire to local concerns, and data collection may be carried out via individual questionnaires or via focus groups. The results will help generate hypotheses that can be investigated with quantitative studies, and they will produce examples of the type of heat prevention interventions used by workers. The application of special heat warning systems, occupational heat exposure guidelines and organised re-hydration programmes can also be analysed.

### ***Quantitative studies of occupational health impacts, work capacity and prevention***

This study component measures the actual difference in health and work capacity effects of heat between seasons with different levels of heat exposure in the same groups of workers. Occupational groups to include are those that would be vulnerable to heat exposure as identified in the pilot-study or qualitative study. The results can be expressed as quantitative exposure–response relationships for different types of effects. The quantitative study provides a basis for estimating future trends in occupational health risks and daily work capacity and economic impacts when climate conditions change. This type of study can also quantify the effectiveness of different methods to reduce heat exposure and impacts (preventive interventions or adaptation methods).

### ***Health and productivity impact assessment of local climate change on occupational health***

With the exposure-response relationships identified with the quantitative studies and local heat exposure estimates, it will be possible to calculate the future impact not only on individuals, but also at population level based on the estimated climate change at a particular place. Additional input data required are the estimated future age distribution and occupation distribution of the population of interest, and the extent to which they are working outdoors and/or indoors, with or without air conditioning or other effective cooling technologies. The results are estimates of the current and future health risks, the lost work hours due to reduced work capacity (a ‘trade-off’ between health risk and work productivity), and potential economic impacts as a function of the degree of climate change at the locality.

Population-based estimates of climate change impacts on occupational health, worker productivity and the economy will enable estimates of how different cooling mechanisms can influence each of these variables, as well as the cost–benefit relationship of various preventive adaptation approaches. The Hothaps team will provide detailed guidance on how each component of the field studies should be carried out.

### ***Conclusions and invitation***

Climate change will pose a number of health threats. The effects on working people have not yet been fully analysed. The aim of the Hothaps programme is to assess the effects of a hotter climate on occupational health and productivity. The physiological and ergonomic basis of these potential effects of climate change is well known, but the impacts in different countries and occupational groups have as yet been only poorly quantified.

The threats to health, well-being and the economy from the ‘Hothaps effect’ strengthens the need for

mitigation of climate change and for preventive interventions (adaptation) through design of urban areas, housing and workplaces that reduce heat exposure, and through public and occupational health programmes that protect individuals at risk.

This article invites interested scientists around the world to join the research programme by carrying out field studies in their locality. Of particular interest are locations in tropical countries where large population groups are working in hot environments without adequate protection from heat.

### Conflict of interest and funding

The authors have not received any funding or benefits from industry to conduct this study.

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