Health and Global Environmental Change
SERIES, No. 2

WORLD HEALTH ORGANIZATION
EUROPE

Heat-waves:
risks and responses

ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

DWD

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Heat-waves: risks and responses

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ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

DWD

Abstract

High air temperatures can affect human health and lead to additional deaths even under current climatic conditions. Heat-waves occur infrequently in Europe and can significantly affect human health, as witnessed in summer 2003. This report reviews current knowledge about the effects of heat-waves, including the physiological aspects of heat illness and epidemiological studies on excess mortality, and makes recommendations for preventive action. Measures for reducing heat-related mortality and morbidity include heat health warning systems and appropriate urban planning and housing design. More heat health warnings systems need to be implemented in European countries. This requires good coordination between health and meteorological agencies and the development of appropriate targeted advice and intervention measures. More long-term planning is required to alter urban bioclimates and reduce urban heat islands in summer. Appropriate building design should keep indoor temperatures comfortable without using energy-intensive space cooling. As heat-waves are likely to increase in frequency because of global climate change, the most effective interventions, measures and policies to protect the health of vulnerable Europeans need to be developed and evaluated.

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Foreword

This important publication, reviewing the effects of heat stress on health and potential strategies to reduce vulnerability to thermal stress, is the work of a strong collaborative team of investigators from several European countries. It is particularly timely given the high-profile effects of the heat-wave in France in 2003 that have reinforced the need for societies to cope more effectively with heat-waves.

The ageing of the European population, together with the potential effects of climate change, may exacerbate the threats to human health posed by thermal stress in the future. Heat-health warning systems offer the potential for collaboration between meteorological agencies and health authorities. However, merely issuing warnings is unlikely to substantially reduce heat-related deaths. Community outreach to vulnerable groups will be necessary, and the impact of such systems must be evaluated to ensure that they deliver the promise of reducing heat-related deaths. The challenge of reducing the effects of thermal stress, especially on elderly people, also requires commitment from policy-makers and building designers to improve indoor environments without using approaches that lead to increases in greenhouse gas emissions. Health researchers and those studying the built environment need to collaborate to determine cost-effective designs to reduce thermal stress.

This publication makes an important contribution to understanding of the effects of thermal stress and effective responses. It complements other work such as that on the health effects of floods and the effects of climate on infectious diseases that has been undertaken under the Climate Change and Adaptation Strategies for Human Health (cCASHh) project. The contributors to this publication are to be congratulated on marshalling existing evidence in an accessible form and indicating research questions that still need to be addressed.

Andy Haines
Dean
London School of Hygiene and Tropical Medicine
United Kingdom

Foreword

When the Climate Change and Adaptation Strategies for Human Health (cCASHh) project started on 1 May 2001, few people would have thought that its results would be so timely.

The heat-wave of August 2003 in Europe and its high toll of victims in various parts of Europe have made it clear once again that no one on this planet will remain unaffected by the effects of climate change. One heat-wave does not prove that the world is getting hotter, but last summer's weather fit a global trend that has seen previous records shattered with increasing regularity. Although the historical data for heat-waves may leave much to be desired, the August heat-wave in Europe has certainly broken all records for heat-induced human deaths.

This publication summarizes the findings of work package 3 of the project Vulnerability Assessment of thermal stresses. It shows that health care and social systems are ill prepared for thermal stresses and that intervention plans and effective technical intervention are lacking. The publication identifies the research gaps and formulates recommendations.

Relatively little research has been carried out on the effects of climate change on human health. This type of research requires an interdisciplinary approach. The cCASHh project is a good example. Coordinated by WHO, it comprises eight partners from six countries and brings together researchers from different disciplines.

Congratulations to all the participants for their hard work in producing this important and comprehensive publication.

Karin Zaunberger
Project Officer
Research Directorate-General
European Commission

Foreword

Human beings are closely linked to the atmospheric environment via their heat budget. Extreme thermal conditions can harm the health of people with limited capacity for acclimatization, as was shown by the heat-wave that struck central, western and southern Europe in August 2003. Heat-waves appear to constitute a great health risk even in moderate climates.

Such extreme events are expected to occur again because of the natural variability of climate and the assumed climate change. Taking appropriate precautionary measures has thus become urgent. The key term is adaptation. The Climate Change and Adaptation Strategies for Human Health (cCASHh) project provides basic findings on the capacity of the population to adapt to extreme thermal conditions and has identified several strategies for reducing vulnerability. Heat health warning systems, with intervention measures adjusted to local conditions, can save lives in critical cases. Long-term goals should include reducing urban heat islands through climate-related urban planning and designing buildings to create favourable indoor climates without the use of air-conditioning. Maximizing the effectiveness of such adaptation measures requires intense multidisciplinary cooperation between experts in numerous fields.

Based on German Federal law, the Deutscher Wetterdienst carries out pure and applied research in public health. This is probably unique among national meteorological services, and the Deutscher Wetterdienst therefore plays an appreciated role in human biometeorology within the World Meteorological Organization. I am very happy to report that there has been close and fruitful collaboration between WHO, the London School of Hygiene and Tropical Medicine and the Deutscher Wetterdienst on this fundamental issue. I would like to thank the European Commission for funding this forward-looking research.

Udo Gärtner
President
Deutscher Wetterdienst
Permanent Representative of Germany with the World Meteorological Organization

Foreword

Severe floods, windstorms, heat-waves and cold-spells have affected the European Region during the last few years. The political, social, environmental and health consequences of these episodes have stimulated debate on whether appropriate action can prevent at least some of the health effects of such extreme weather and climate events.

The current increasing instability of the global climate system is predicted to potentially lead to an increase in climate variability. In particular, the frequency and intensity of extreme temperatures is expected to change. An unprecedented heat-wave affected the European Region in summer 2003, causing excess mortality in France, northern Italy and Portugal.

The assessment of the environmental and health effects of this and previous heat-waves has highlighted a number of knowledge gaps and problems in public health responses. To date, heat-waves have not been considered a serious risk to human health with "epidemic" potential in the European Region. Reducing the health impact of future heat-waves requires addressing fundamental questions, such as whether heat-waves can be predicted, detected and prevented and how this can be achieved. Knowledge gaps exist in the relationship between heat exposure and a range of health outcomes; in understanding interactions between harmful air pollutants and extreme weather and climate events; in harmonizing episode analysis; and in evaluating the effectiveness of heat-related public health interventions. There is ongoing debate on whether and how to develop heat health warning systems, to provide space cooling in specific locations and to develop public advice and community-based activities that support the social and health-related welfare of elderly people and other high-risk groups to reduce their vulnerability to temperature extremes. Cost–effectiveness analysis will be needed.

Public health authorities have started to respond to these challenges and have initiated some programmes to prepare populations and increase their capacity to tolerate extreme weather events; however, more work needs to be done to describe these responses and to evaluate their effectiveness.

This publication summarizes the main findings of reviews carried out within the cCASHh (Climate Change and Adaptation Strategies for Human Health) project, coordinated by the WHO Regional Office for Europe. In particular, this report addresses physiological and epidemiological aspects of heat stress and assesses measures for reducing mortality and morbidity from heat stress such as heat health warning systems, urban planning and indoor climate.

We are confident that this publication will contribute to further stimulating debate and research on this subject, supporting the efforts of public health authorities to better target intervention strategies for prevention.

Roberto Bertollini
Director
Division of Technical Support, Health Determinants
WHO Regional Office for Europe

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Christina Koppe (Deutscher Wetterdienst, Business Unit Human Biometeorology, Freiburg, Germany), Sari Kovats (Centre on Global Change and Health, London School of Hygiene and Tropical Medicine, United Kingdom) and Gerd Jendritzky (Deutscher Wetterdienst, Business Unit Human Biometeorology, Freiburg, Germany) were the main authors.

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The coordinators and authors would like to thank the following people for participating in the cCASHh Workshop on Vulnerability to Thermal Stresses, 5–7 May 2003, Freiburg, Germany organized by the Deutscher Wetterdienst and WHO and the very useful suggestions received during this meeting: Teresa Abrantes, Instituto de Meteorologia, Centro de Analise e Previsao do Tempo (CAPT), Lisbon, Portugal; Tanja Cegnar, Environmental Agency, Ljubljana, Slovenia; Aline Chiabai, Fondazione Enrico Mattei, Venice, Italy; Hans-Martin Füssel, Potsdam Institute for Climate Impact Research (PIK), Department for Integrated Systems Analysis, Potsdam, Germany; Peter Höppe, Institut für Arbeits und Umweltmedizin der Universität München, Munich, Germany; Gudrun Laschewski, Deutscher Wetterdienst, Business Unit Human Biometeorology, Freiburg, Germany; Michael van Lieshout, Integrated Assessment Scientist, International Centre for Integrative Studies (ICIS), Maastricht, the Netherlands; Anna Paldy, Fodor Jozsef National Center for Public Health, National Institut of Environmental Health, Budapest, Hungary; and Thomas Voigt, European Topic Centre/Air and Climate Change, Berlin, Germany.

1.INTRODUCTION

A changing climate is expected to increase average summer temperatures and the frequency and intensity of hot days. Heat-waves in Europe are associated with significant morbidity and mortality. A preliminary analysis of the 2003 heat-wave in Europe estimated that it caused 14 802 excess deaths in France (National Institute of Public Health Surveillance, 2003), 2045 excess deaths in the United Kingdom, 2099 in Portugal. Ongoing epidemiological studies will better describe and contribute substantial evidence to the understanding of health effects of heat-waves in Europe and add significantly to targeting interventions.

This report summarizes the main findings of reviews carried out within the cCASHh (Climate Change and Adaptation Strategies for Human Health) project and a consultative workshop with experts and stakeholders from 10 countries. It addresses the health impact of heat, aspects of prevention and adaptation such as heat health warning systems, urban planning elements and aspects of building design.

This study was funded by the European Commission. The key objectives of the overall cCASHh project are:

- to identify the vulnerability of European populations to the adverse effects of climate change on human health;
- to review current measures, technologies, policies and barriers related to improving the capacity of human populations to adapt to climate change;
- to identify the measures, technologies and policies and approaches to implementation that are most effective and appropriate for European populations to successfully adapt to climate change;
- to provide estimates of the health benefits of specific strategies or combinations of strategies for adaptation for vulnerable populations under various climate change scenarios; and
- to estimate the costs (of climate-related damage and implementing adaptive measures) and benefits (both of climate change and of adaptation strategies), including auxiliary benefits independent of climate change.

The research project covers the 15 current European Union countries and the 10 countries that are scheduled to accede to the European Union in 2004. In some cases, however, assessment was extended to countries in the eastern part of the WHO European Region. The project is scheduled to be completed by July 2004.

To achieve these objectives, vulnerability assessment, a conceptual framework for adaptation, policy analysis, economic analysis and scenarios will be applied to thermal stress, floods, vector-borne diseases and waterborne and foodborne diseases.

The research within the cCASHh project is divided into 11 work packages. Work package 3 deals with vulnerability to thermal stress and has the following objectives:

- to identify populations in Europe that are particularly vulnerable to heat stress and to identify and reduce this vulnerability; and
- to identify and evaluate strategies for adaptation.

Within this work package, the Deutscher Wetterdienst, the London School of Hygiene and Tropical Medicine reviewed available literature, conducted a qualitative assessment of heat warning systems in Europe and conducted time-series analysis of mortality and weather parameters in a number of European cities. The WHO European Centre for Environment and Health in collaboration with the Deutscher Wetterdienst and the London Scool of Hygiene and Tropical Medicine organized the cCASHh Workshop on Vulnerability to Thermal Stresses on 5–7 May 2003 in Freiburg, Germany:

- to identify the potential impact of climate change on heat-related morbidity and mortality;
- to review and evaluate existing short-term and long-term adaptation measures;
- to make recommendations for implementing and evaluating heat health warning systems and other appropriate strategies to reduce heat stress; and
- to identify information gaps and research needs.

During the Workshop, the current state of knowledge of the potential to reduce heat stress through urban planning and heat health warning systems was presented, with a focus on developing criteria for evaluating their effectiveness.

The Deutscher Wetterdienst, Business Unit Human Biometeorology in Freiburg, Germany kindly hosted the Workshop. Experts were asked to prepare short presentations (Annex 1).

There are still many knowledge gaps, however this report should help to stimulate debate and plan responses to heat-waves in the future.

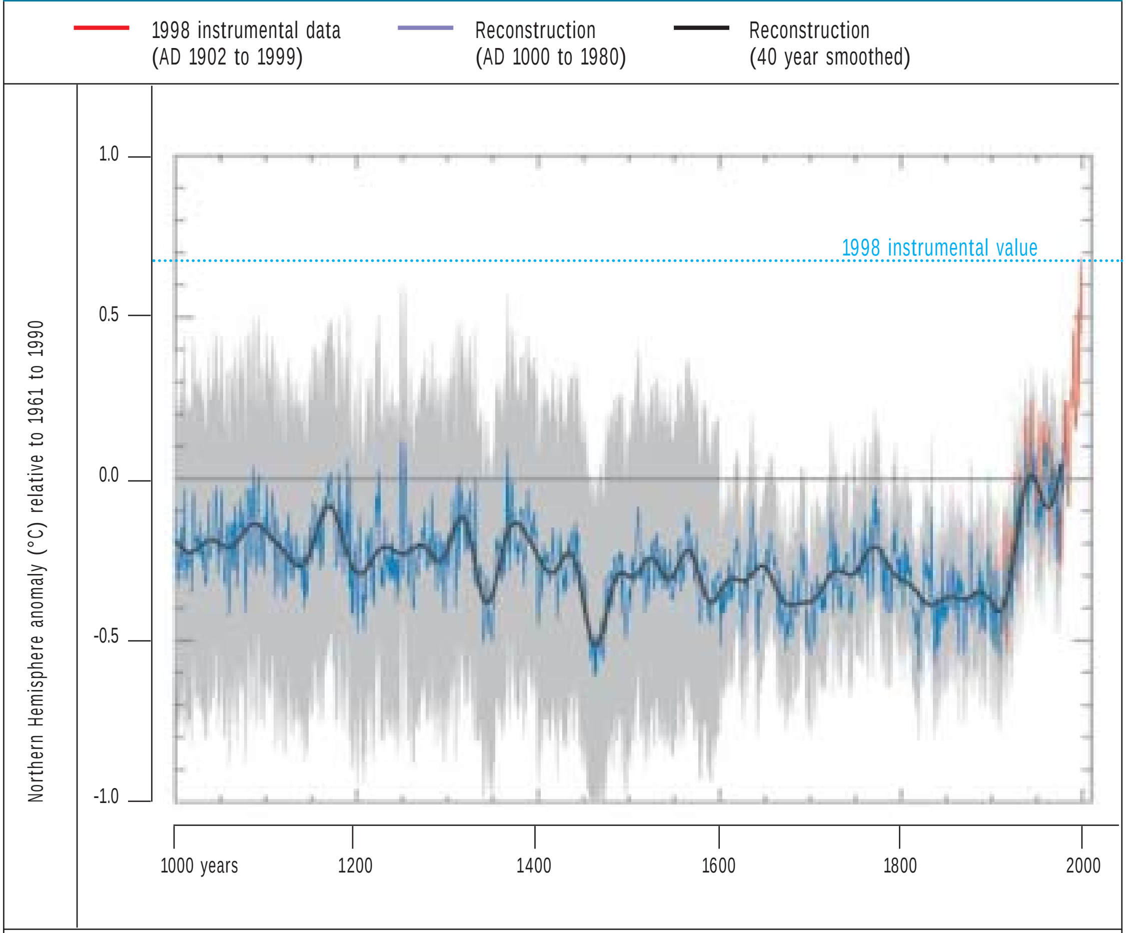
2. CLIMATE CHANGE AND TEMPERATURE EXTREMES

2.1. Observed changes in the frequency and intensity of heat-waves

The Third Assessment Report of the Intergovernmental Panel on Climate Change (Houghton et al., 2001) stated that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities". Detecting climate change is difficult because any climate change "signal" is superimposed on the background "noise" of natural climate variability. Nevertheless, there is now good evidence that the climate is changing. The global average land and sea surface temperature increased by 0.6 ± 0.2 °C over the 20th century (Houghton et al., 2001). Nearly all of this increase occurred in two periods: 1910–1945 and since 1976 (Fig. 1). At the regional scale, warming has been observed in all continents, with the greatest temperature changes occurring at middle and high latitudes in the Northern Hemisphere.

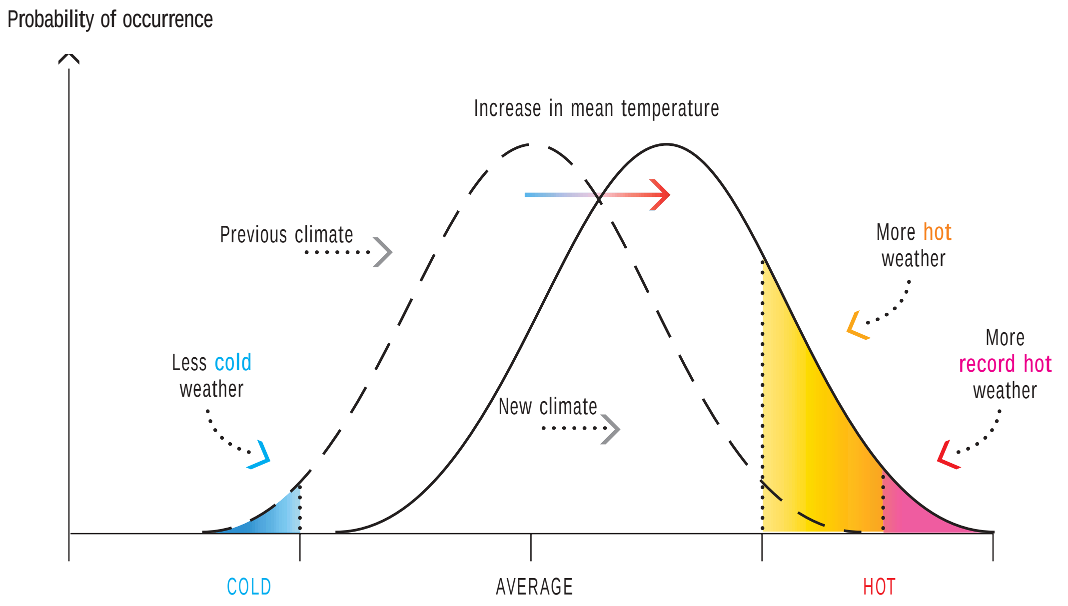
Extreme weather events are, by definition, rare stochastic events. With climate change, even if the statistical distribution of such events remains the same, a shift in the mean will entail a nonlinear response in the frequency of extreme events (Fig. 2).

Fig. 1. Variation of the surface temperature of the Northern Hemisphere over the last millennium



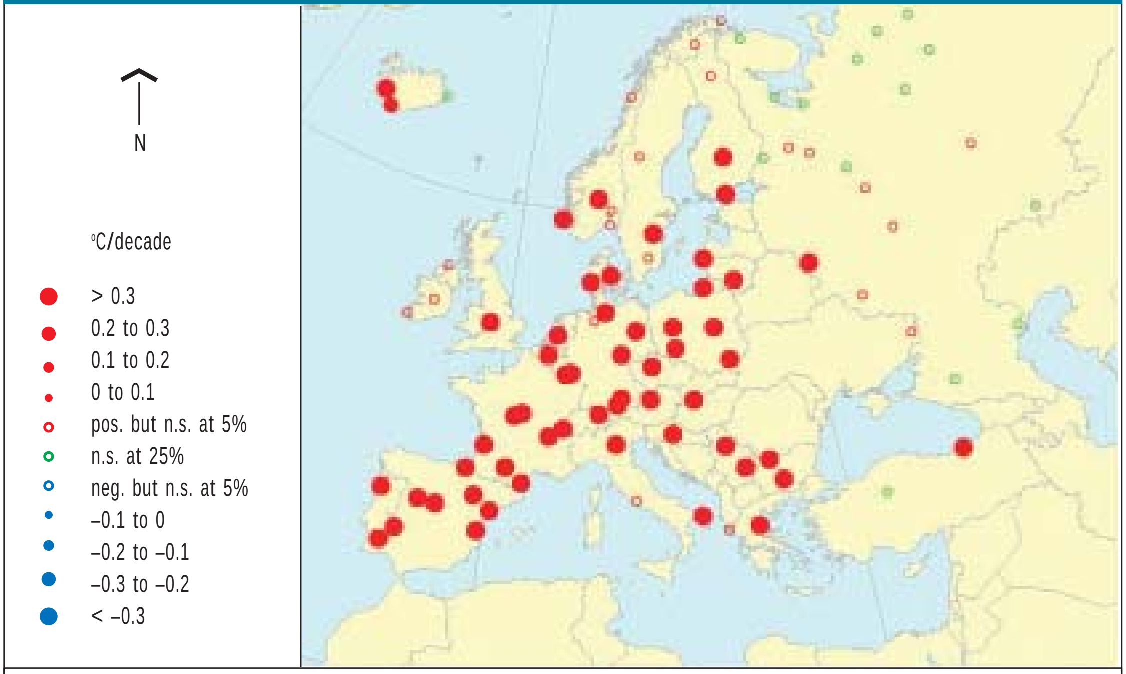
Source: Houghton et al. (2001).

Fig. 2. Changes in the probability of extreme weather events



Source: Houghton et al. (2001).

Fig. 3. Change of daily maximum temperatures (°C per decade) in the summer half-year, 1976–1999



Source: Klein Tank et al. (2002).

2.1. Observed changes in the frequency and intensity of heat-waves

Few studies have looked at the instrumental record to determine whether the frequency or intensity of temperature extremes has changed (IPCC). Houglton et. al, "developed estimates of confidence in observed and projected changes in extreme weather events". Higher minimum temperatures seem to be very likely to occur. This is partly because long data series are required of sufficient quality and are often not available. Analyses using monthly gridded temperature data around the world since 1951 indicate that the recent increase in global surface temperatures is accompanied both by reductions in the areas affected by extremely low temperatures and by increases in the areas with extremely high temperatures.

Analyses of proxy data for the Northern Hemisphere indicate that the increase in temperature in the 20th century is likely to have been the largest in any century during the past 1000 years (Fig. 1). Although the trend towards warmer average global surface temperatures has been uneven over the last century, the trend for the period since 1976 is roughly three times that for the past 100 years as whole. Global climate change is likely to be accompanied by an increase in the frequency and intensity of heat-waves as well as by warmer summers and milder winters. The European climate assessment (Klein Tank et al., 2002) confirms that Europe has experienced an unprecedented rate of warming in recent decades. From 1976 to 1999, the annual number of warm extremes increased twice as fast as expected based on the corresponding decrease in the number of cold extremes. During this period, minimum (night-time) temperatures increased more strongly than maximum (day-time) temperatures. Fig. 3 illustrates the trends in daily maximum temperatures in Europe for the period 1976–1999. The frequency of very hot days in central England has increased since the 1960s, with extreme summers in 1976, 1983, 1990 and 1995 (Hulme et al., 2002). Sustained hot days (taken as heat-waves) have become more frequent, especially in May and July.

2.2. Heat-waves and future climate change

Recent scientific assessments indicate that, as global temperatures continue to increase because of climate change, the number and intensity of extreme events are likely to increase (World Meteorological Organization, 2003). New record extreme events occur every year somewhere around the globe, but in recent years the numbers of such extremes have been increasing.

Table 1 depicts an assessment of confidence in observed changes in extremes of weather and climate during the latter half of the 20th century (left column) and in projected changes during the 21st century (right column). This assessment relies on observational and modelling studies as well as the physical plausibility of future projections across all commonly used scenarios and is based on expert judgement (Houghton et al., 2001).

The impact of extreme summer heat on human health may be exacerbated by increases in humidity. Heat-waves usually occur in synoptic situations with pronounced slow air mass development and movement, leading to intensive and prolonged heat stress. However, even short or moderate heat episodes adversely affect human health.

TABLE 1. ESTIMATES OF CONFIDENCE IN OBSERVED AND PROJECTED CHANGES IN EXTREME WEATHER AND CLIMATE EVENTS

Confidence in observed changes (latter half of the 20th century)	**Changes in phenomenon**	**Confidence in projected changes (during the 21st century)**
Likely	Higher maximum temperatures and more hot days over nearly all land areas	Very likely
Very likely	Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely
Very likely	Reduced diurnal temperature range over most land areas	Very likely
Likely over many areas	Increase of heat index (combination of temperature and humidity) over land areas	Very likely over most areas

Source: adapted from Houghton et al. (2001).

3. THE IMPACT OF HEAT ON HUMAN HEALTH

3.1. Physiological aspects of temperature regulation

3.2. Epidemiological studies of heat

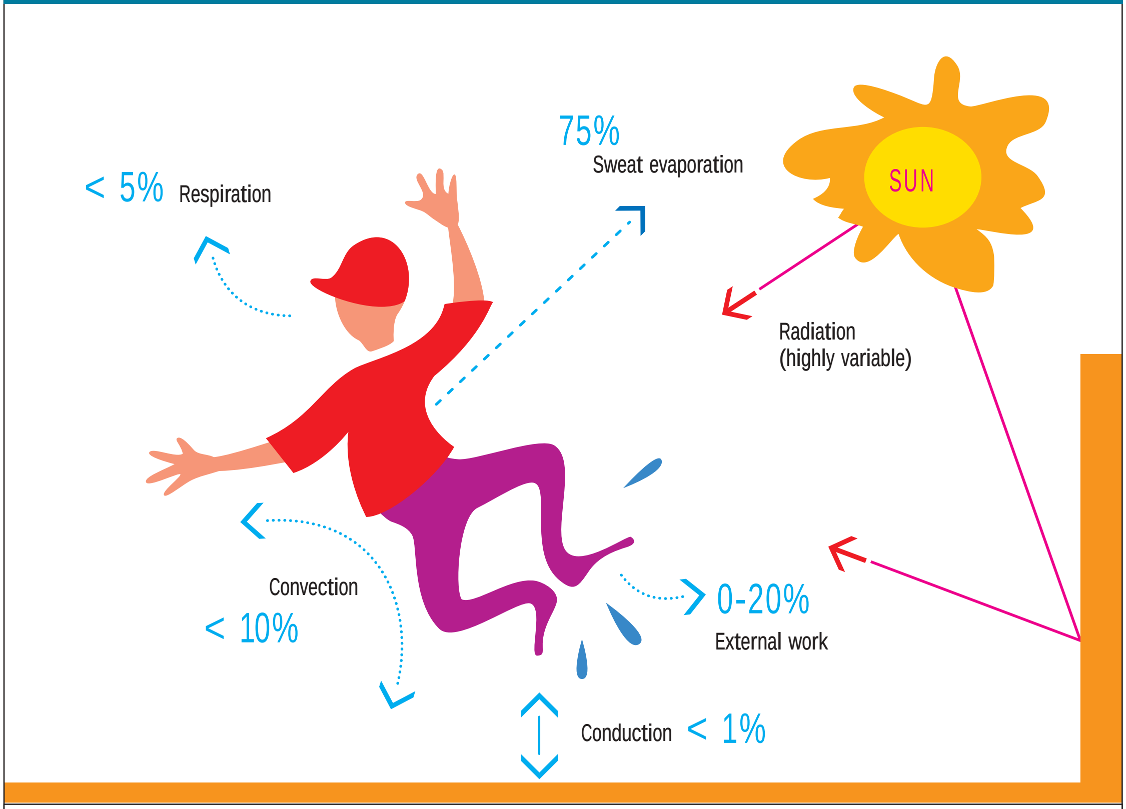
3.1. Physiological aspects of temperature regulation

3.1.1. Mechanisms of heat exchange

The body temperature regulation centres in the brain (hypothalamus) attempt to keep the body core temperature within healthy limits. At rest this is about 37 °C, but with exercise the temperature can increase to 38–39 °C without any detrimental effect on health, as long as the thermoregulatory system is within its control range.

Staying within the control range (the predictive zone) requires the body to balance heat production by the body and possible other heat gains (such as solar radiation) with heat loss. Heat is produced as a result of the metabolic activity required to perform activities. Most of the energy the body uses is released as heat. The body can lose this heat by convection (warming of air or water around the body), by conduction (contact with solids, such as the floor), respiration (air inhaled is usually cooler and dryer than exhaled air) radiation and evaporation of sweat (Fig. 4). When air temperature and water vapour pressure increase, the gradients between skin and environment required for these heat losses decrease and heat loss is reduced. When air temperature approaches skin temperature, heat loss by convection approaches zero, and heat may even be gained when air temperature rises above skin temperature. In these cases the main (and sometimes only) avenue left for losing heat is by producing sweat and

Fig. 4. Heat gains and heat losses in hot environments



Source: adapted from Havenith (2003).

evaporation, and even this is compromised with increasing vapour pressure. Heat production then exceeds losses and the body temperature increases.

Several effector mechanisms inside the body are involved in regulating body temperature. The most important ones for heat are sweat production to lose heat from the skin and skin blood flow to transport heat from the body core and the muscles to the skin. During heat stress, the proper functioning of both systems is essential for thermal regulation. If they are unduly stressed and cannot match the thermoregulatory demands, this leads to excessive strain on the body and eventually may cause heat illness. Additional effector mechanisms are an increase in some hormones (antidiuretic hormone and aldosterone), in respiratory rate and in heart rate.

For body temperature to remain stable (heat storage = 0), heat loss needs to balance heat production.

The heat balance can be written as (Havenith, 2002):

Heat storage = heat production – heat loss = (metabolic rate – external work) – (conduction + radiation + convection + evaporation + respiration)

Even heat loss components can lead to heat gain under certain circumstances. The environmental factors listed in Table 2 influence the heat loss components and should therefore be considered in assessing heat stress.

TABLE 2. ENVIRONMENTAL FACTORS AND THEIR EFFECTS ON THE HUMAN HEAT BALANCE

Environmental factor	Effect on human heat balance	Explanation
Air temperature	T(skin) > T(air) T(skin) < T(air)	Convective heat loss from the skin to the environment Convective heat gain from the environment to body skin
Radiant temperature	Radiant heat exchange between skin and environment	In the sun, radiant temperature can easily exceed temperature, which results in radiant heat transfer from the environment to the skin
Surface temperature	Conductive heat exchange (minor role)	
Air humidity	Evaporative heat loss or gain	The amount of moisture (not relative humidity!) in the air determines whether moisture (sweat) in vapour form flows from the skin to the environment or vice versa. Evaporation of sweat is the most important avenue for the body to dissipate its surplus heat.
Wind speed	Convection and evaporation	Heat exchange increases with increasing wind speed

3.1.2. Heat-related illness

Skin eruptions, heat fatigue, heat cramps, heat syncope, heat exhaustion and heat stroke are classical heat-related illnesses. Most heat-related illnesses (except for skin eruptions and heat cramps) are in essence consequences of varying severity of failure in the thermoregulatory system.

The least severe form is heat syncope, caused by a failure of the circulation to maintain blood pressure and supply oxygen to the brain. As soon as the patient is horizontal, the system recovers quickly. The decline in blood pressure is related to a reduction in venous return, caused by the expansion of the circulatory volume by dilation of skin arteries and veins, often combined with lowered plasma volume because of dehydration. This is exacerbated when no muscle pump (activity) is present to support the venous return of blood to the heart (such as a soldier standing still in a parade).

When the muscle pump is active (such as during exercise), blood pressure can be kept up longer and body heating may progress further, together with high cardiovascular stress, leading to heat exhaustion. If the high heat load from exercise and/or climate in such cases is not removed, this may progress into heat stroke, in which extreme body temperature (above 40.5 °C) leads to damage to cellular structures and the thermoregulatory system with a high risk of mortality. This typically is diagnosed in fit young adults who continue exercising despite feeling unwell, such as during competitions. Heat stroke has a high case–fatality ratio and a rapid onset. Complications of heat stroke include adult respiratory distress syndrome, kidney failure, liver failure and disseminated intravascular coagulation (Donoghue et al., 1997). Severe functional impairment was observed in 33% of 58 patients admitted with heat stroke during the Chicago heat-wave, with no improvement after 1 year in those still alive (Dematte et al., 1998). Deaths from heat stroke may be underreported because heat stroke is similar to other more familiar causes of death, especially coronary or cerebral thrombosis, once the body is no longer hot itself or in a hot environment (Keatinge et al., 1986; Mirchandani et al., 1996).

For less fit subjects (such as some elderly people), heat-related illnesses can occur at low levels of exercise or even in the absence of exercise. Low fitness levels lead to a low cardiovascular reserve and

TABLE 3. SYMPTOMS OF DEHYDRATION ACCORDING TO THE PERCENTAGE OF BODY WEIGHT

Degree of dehydration	Liquid loss (litres) for a 70-kg person	Symptoms
2%	1.4	Thirst
4%	2.8	plus dry mouth
6%	4.2	plus increased heart rate and increased body temperature
8%	5.6	plus swollen tongue, difficult speech, reduced mental and physical performance
12%	8.4	Recovery only after parenteral fluid administration
14%	9.8	Rapid temperature increase and death

Source: adapted from Havenith (2003).

thus to low heat tolerance. In addition, several other predisposing factors can accelerate the development of high body temperatures. Similar to fitness, these mostly affect the sweating system (reduced cooling), skin vasodilation (reduced heat movement from core to skin) or cardiovascular reactivity (problems with supply to vital organs and with blood pressure).

However, even when exposure is less severe, these processes in reaction to heat can also affect health through other pathways. The increased cardiovascular load in heat (vasodilation and dehydration) exacerbates other health problems such as cardio-vascular disease. Some cause-and-effect relationships with heat are unclear apart from the additional strain on the system caused by heat, but coronary and cerebral thrombosis are thought to be related to the loss of water and salt in warm environments leading to haemoconcentration and a thrombogenic increase in viscosity and the density of platelets and red blood cells.

Increased sweat production in heat can lead to dehydration. A fit, acclimatized person can produce up to 3 litres of sweat per hour; a normal person produces up to 1 litre of sweat per hour. Table 3 lists the symptoms of dehydration.

3.1.3. Predisposing factors for heat-related illnesses

The main predisposing factors for heat-related illness are:

- age;
- lack of acclimatization;
- dehydration because of reduced food and liquid uptake, intestinal problems, use of diuretics and alcohol abuse;
- use of other drugs affecting the temperature regulation system, such as phenotiazines and barbiturates and other medications;
- low fitness;
- overweight; and
- fatigue, sleep deprivation, long-term high-level exercise and protective clothing.

3.1.3.1. Responses in elderly people

Older people are more vulnerable to heat because of intrinsic changes in the regulatory system and/or because of the presence of drugs that interfere with normal homeostasis. Few studies of physiological heat tolerance have been undertaken in older (>65) people (Drinkwater & Horvath, 1979; Basu & Samet, 2002). As homeostasis is impaired, elderly people may not be aware that they are becoming ill from high temperatures and therefore may not take action to reduce their exposure. Several studies have shown that elderly people in institutions, such as residential care homes, are vulnerable to heat-related illness and death (Bull & Morton, 1975; Lye & Kamal 1977; Faunt et al., 1995; Pajares Ortiz et al., 1997).

Havenith et al. (1995) studied the response to heat stress in a warm, humid environment in a heterogeneous sample of 56 subjects aged 20–73 years. The effect of age on body temperature and sweating was negligible compared with effects related to maximum oxygen uptake (as an indicator for fitness). Chronological age, however, independently affected cardiovascular effector response.

Low fitness is one factor that makes elderly people susceptible to heat-related morbidity and mortality. Another factor is the relatively high percentage of people with illnesses and disabilities within the elderly population. In the United Kingdom, 41% of people aged 65–74 years and 52% of those 75 years or older reported that their lifestyle was limited by illness or disability versus 22% among all age groups (Havenith, 2001a). This also influences well-being in various thermal environments. In addition, medication use associated with illness often adversely affects thermoregulation (Havenith, 2001a).

Since elderly people have reduced sweating capacity, it is essential that the sweat they produce evaporates (Havenith, 2001a). This does not happen if ambient water vapour pressure is high. This fact stresses the importance of examining not only air temperature in analysing heat-related morbidity and mortality but also water vapour pressure, or an atmospheric moisture equivalent.

3.1.3.2. Physiological acclimatization

Short-term heat acclimatization usually takes 3–12 days (Table 5), but complete (long-term) acclimatization to an unfamiliar thermal environment may take several years (Babayev, 1986; Frisancho, 1991). Acclimatization includes several mechanisms (Table 4) and has been studied in sports medicine, including improved thermal comfort and exercise performance.

As long as sweating is continuous, people can withstand remarkably high temperatures, provided that water and sodium chloride, the most important physiological constituents of sweat, are replaced.

Short-term heat acclimatization leads to sweat appearing at the skin surface, at a lower body temperature. It increases the maximal sweat volume and lowers the salt concentration (Hori, 1995).

TABLE 4. PHYSIOLOGY OF HEAT ACCLIMATIZATION

Increased thermal comfort	Increased exercise performance
Core temperature – reduced	Cardiovascular stability – improved • Heart rate – lowered • Stroke volume – increased • Blood pressure – better maintained • Myocardial compliance – increased
Sweating – improved • Earlier onset • Higher rate • Redistribution • Resistance to hydromeiosis	Fluid balance – improved • Thirst – increased • Electrolyte loss – reduced • Total body water – increased • Plasma volume – increased and better defence
Skin blood flow – increased • Earlier onset • Higher flow	
Metabolic rate – lowered	

Source: Armstrong, 1998

In addition, acclimatization results in a reduced core temperature threshold for skin vasodilation. Venoconstrictor tone also increases during the first day of acclimatization (Havenith, 2001b). Short-term acclimatization gradually disappears over a period of several weeks after the heat stress ends. Table 5 lists several studies of the time required to gain or to lose short-term heat acclimatization.

In most of these studies, people have spent several hours per day in the environment to which they were to acclimatize. Comparing the studies directly is difficult, however, because exposure patterns differ.

In contrast to short-term adaptation, long-term adaptive changes are stable and remain for a long period. Long-term adaptation results in less sweat with a lower salt intake, a lower rise in core temperature and a lower increase in heart rate at a given heat load (Hori, 1995).

TABLE 5. STUDIES OF SHORT-TERM HEAT ACCLIMATIZATION

Acclimatization indicator	Days	Reference
Acclimatization gain		
Sweat rate	3–4	Hori (1995)
Rectal temperature, heart rate	8	Williams & Heyns (1969)
Sweat rate	< 8	
Heart rate, plasma volume expansion and perceived exertion decrease	4–5	Armstrong & Dziados (1986)
Renal NaCl decrease	5–6	
Rectal temperature decrease	6–7	
Sweat NaCl decrease	7–8	
Sweat rate increase	10–12	
Acclimatization loss		
Rectal temperature		Williams et al. (1967)
25% loss of acclimatization	7	
40% loss of acclimatization	14	
50% loss of acclimatization	21	
Heart rate		
40% loss of acclimatization	7	
75% loss of acclimatization	14	
90% loss of acclimatization	21	
Sweat rate		
65% loss of acclimatization	7	
80% loss of acclimatization	14	
100% loss of acclimatization	21	

3.1.3.3. *Dehydration*

Sufficient fluid intake during heat-waves is essential. Dehydration seems to be a critical factor in contributing to heat mortality, in particular in the frail and older populations. The prevalence of inadequate hydration or dehydration for elderly residents of nursing homes was determined to be 33% (Colling et al., 1994 and Mentes et al., 1999 cited in Mentes & Culp, 2003); 50–92% of nursing homes residents had inadequate fluid intake (Chidester & Spangler, 1997 cited in Mentes & Culp, 2003). Patients in long-term care who were assessed as confused using the Cognitive Assessment Scale, had significantly lower intake of fluid over 24 hours than lucid patients (Hodgkinson et al., 2003). The presence of multiple diseases and/or treatment puts elderly nursing home residents at risk for dehydration (Hodgkinson et al., 2003). Alcohol depresses the central nervous system and through increased diuresis can further aggravate dehydration.

Age, mobility and functional ability, gender, visual impairment, speaking ability, incontinence and the frequency of ingestion sessions were associated with higher risk of dehydration in 17 reviewed articles (Hodgkinson et al., 2003). Incontinence was not found to be a statistically significant risk factor for dehydration. However, it was a risk factor for significantly lower fluid intake compared with continent subjects (Hodgkinson et al., 2003).

In fact, the insidious state of chronic underhydration becomes a physiological balancing act in which frail elderly people become increasingly susceptible to minor environmental or physiological stressors that can precipitate dehydration and subsequent acute health problems. The ramifications of chronic underhydration are further obscured by the fact that, once an elderly individual is hospitalized and treated for an acute health crisis such as pneumonia, the antecedent condition of underhydration is often overlooked (Mentes & Culp, 2003). Strategies for providing adequate fluids (in an experimental study) included standardized 180 ml of fluid intake with each medication administration, fluid rounds in morning and evening and "happy hours" or "tea time" twice a week in the late afternoon (Mentes & Culp, 2003). The recommended daily intake of fluids should not be less than 1600 ml per 24 hours to ensure adequate hydration.

When heat stress levels are low, there is a small chance of hyperhydration (over drinking), leading to hyponatremia. This typically occurs in young, fit persons participating in sporting events of long duration.

3.1.3.4. *Fitness*

Age and illness are strong predictors in this sense, as age highly correlates with increasing illness, disability, drug use and reduced fitness. Havenith et al. (1995) found that, in general, the higher the maximal oxygen uptake (indicating aerobic fitness) of an individual and/or the larger the individual, the lower the heat strain observed in a warm humid climate (air temperature 35 °C, 80% relative humidity).

Physical fitness tends to decrease with age because the average level of physical activity declines. More strain is placed on the cardiovascular system and less cardiovascular reserve is left, because any activity performed becomes more stressful. The cardiovascular reserve is especially relevant to the capacity for thermoregulation, as it determines the capacity to move heat for dissipation from the body core to the skin by blood flow. Decline in fitness can cause a vicious circle, as the increased strain experienced with activity may promote even further reduction in activity, which again may further reduce fitness. In addition, exposure to heat and cold is avoided, which leads to a loss of acclimatization to heat and cold.

At the population level, these and other changes reduce muscle strength, work capacity, the ability to transport heat from the body core to the skin, hydration levels, vascular reactivity and cardiovascular stability (blood pressure) among elderly people. These effects will place elderly people at a higher risk in extreme conditions, leading to an increase in morbidity and mortality (Havenith, 2001a).

3.1.3.5. Overweight

Overweight is another factor that increases the risk of heat-related illnesses and is often correlated with low fitness levels. The thermal conductivity of fatty tissues (about 200 $W \cdot m^{-1} \cdot K^{-1}$) is lower than that of other tissues in the body (such as muscles, about 400 $W \cdot m^{-1} \cdot K^{-1}$). Subcutaneous tissue is therefore an insulative barrier to conductive heat flow. In an obese person, less heat can be produced per unit mass before the temperature of the core tissues increases. To dissipate heat, obese people have to direct more blood flow through the subcutaneous vessels, and obese people therefore have higher cardiovascular strain and higher heart rates when exposed to heat stress. For these reasons, obese people are more susceptible to moderate heat stress, injuries and heat stroke. However, the difference in heat strain between obese and lean individuals appears to diminish when air temperature exceeds skin temperature. When environmental temperatures surpass skin temperatures, the lean individual will gain heat through radiation and convection at a quicker rate per unit mass (Anderson, 1999). Havenith et al. (1995) state that anthropometric measures and body composition significantly but secondarily influence physiological responses, such as mean arterial blood pressure, forearm blood flow and forearm vascular conductance.

3.2. Epidemiological studies of heat

3.2.1. How should heat episodes be defined?

Heat-waves are rare events that vary in character and impact even in the same location. Arriving at a standardized definition of a heat-wave is difficult; the World Meteorological Organization (WMO) has not yet defined the term. However, several approaches can be used to define a heat-wave.

A heat-wave can be defined based on an absolute or a relative threshold of weather variables or as a combination of both. A relative threshold has the advantage of accounting for local differences in the perception of heat.

A survey of the meteorological services in Europe showed that an operational definition of heat-wave is applied in some countries. These definitions are based on:

- air temperature threshold; or
- air temperature threshold and minimum duration; or
- indices based on a combination of air temperature and relative humidity.

The temperature thresholds used in the definitions in Europe have a north–south and a west–east gradient. The more the country is situated in the south-east, the higher the threshold. This was expected, because summers are usually hotter in southern and continental Europe than in the part of Europe that is influenced by the Atlantic Ocean.

In addition, the length of the summer season and the rate of temperature change can be included in the definition of a heat-wave to be able to incorporate the concept of short-term acclimatization over the summer. There is good evidence that heat-waves early in the summer have greater effects on heat-related morbidity and mortality than heat-waves later in the summer (Hajat et al., 2002).

3.2.2. How should deaths be attributed to heat episodes?

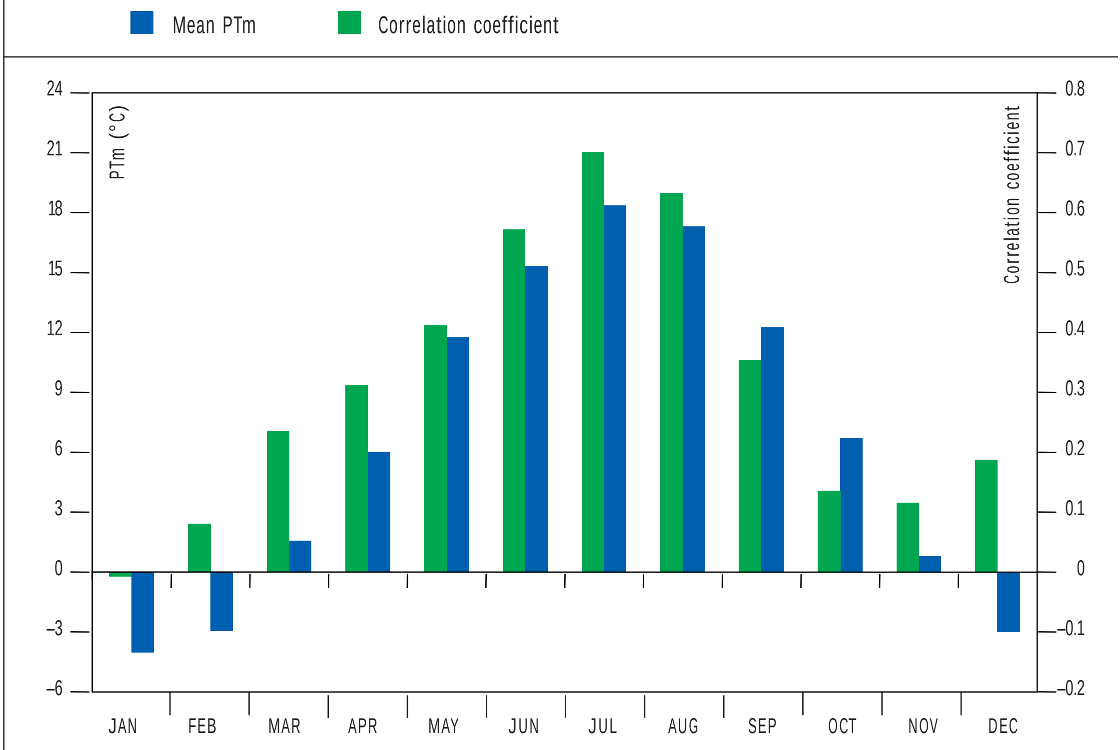
Ambient thermal conditions are an important type of environmental exposure and are responsible for a quantifiable burden of mortality and morbidity. A range of epidemiological methods have been used to estimate the effect of the thermal environment on mortality and morbidity and thus estimate temperature-attributable mortality.

Fig. 5 shows the mean monthly correlation coefficient for the smoothed residuals of perceived temperature[1] and total mortality rate based on 30 years of data from Baden-Württemberg (southwestern Germany). During the warmest months of the year (June, July and August), the correlation coefficient is between 0.5 and 0.7, which indicates that the thermal environment (described by the perceived temperature) has a relatively high impact on mortality for an environmental factor. The relationship between temperature and mortality and morbidity has been studied using different epidemiological designs, such as descriptive studies on heat-waves, mapping studies, time–series studies, case–control studies and case–crossover studies. Time–series studies are an efficient design for analysing the relationship between temperature (or other climate parameters) and mortality for populations in single and multiple regions over long time periods. These methods are considered sufficiently rigorous to

[1] *Perceived temperature (°C) is the air temperature of a reference environment in which the perception of heat and/or cold would be the same as under the actual conditions.*

assess short-term associations (day-to-day and week-to-week) between environmental exposure and mortality if such factors as the seasonal cycle and other long-term trends are adjusted for. Time–series methods are used to quantify the relationship between mortality and temperature across the whole temperature range. A linear relationship derived from such a time–series study is fitted above and below a threshold temperature where mortality is lowest (Fig. 6). This threshold reflects adaptation to the local climate (Keatinge et al., 2000).

Fig. 5. Correlation coefficient between the smoothed residuals of perceived temperature (PTm) and total mortality rate in Baden-Württemberg (southwestern Germany), 1968–1997



The residuals are the deviation of the daily values from the filtered data (101-day Gaussian filter).

The mortality impact of individual heat-wave events has been estimated using descriptive episode analyses. Several studies have shown that deaths from heat-related causes in the International Classification of Diseases are underreported in mortality statistics. A 10-day heat-wave in Athens in 1987 resulted in 926 deaths classified as heat-related. However, the attributable excess mortality was estimated to be more than 2000 (Katsouyanni et al., 1988).

Many studies estimate or calculate attributable or "excess" mortality from heat episodes. Excess mortality is estimated by subtracting the "expected" mortality from the observed mortality. The expected mortality is calculated using a variety of measures, including moving averages and averages from similar time periods in previous years. Estimates are therefore very sensitive to the method used to estimate the "expected" mortality (Whitmann et al., 1997; Kovats & Koppe, forthcoming). Published studies have used different methods, and this makes comparison difficult (Table 6).

Comparing the results of the various national assessments carried out during the heat-wave in 2003 is very difficult. For example, preliminary analysis of the 2003 heat-wave in France estimated that it caused

3.2. Epidemiological studies of heat

Fig. 6. Relationship between maximum daily temperature and mortality in a European city

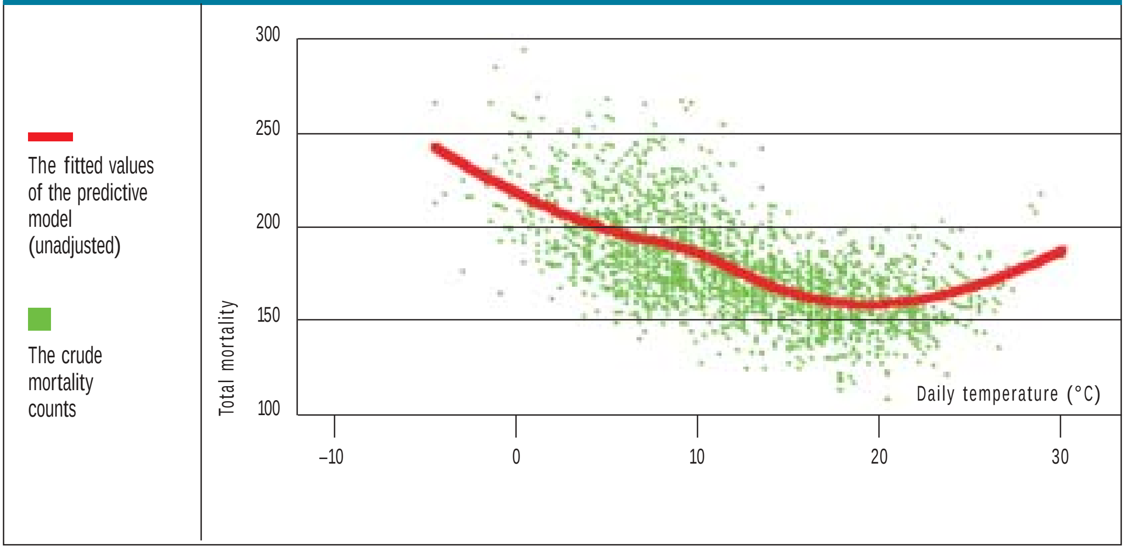


TABLE 6. HEAT-WAVES IN EUROPE: EPISODE ANALYSES

Heat-wave	Attributable mortality	Reference
Birmingham, England, 1976	Number of deaths increased by 10%; excess seen primarily in men and women 70–79 years	Ellis et al. (1980)
London, England, 1976	9.7% increase in England and Wales and 15.4% in Greater London. Almost two-fold increase in mortality rate among elderly hospital inpatients (but not other inpatients)	Lye & Kamal (1977)
Portugal, 1981	1906 excess deaths (all causes, all ages) in Portugal, 406 in Lisbon (in July), including 63 heat deaths	Garcia et al. (1999)
Rome, Italy, 1983	65 heat stroke deaths during heat-wave in the Latio region. 35% increase in deaths in July 1983 compared with July 1982 among those 65 years or older in Rome	Todisco (1983)
Athens, Greece, 1987	2690 heat-related hospital admissions and 926 heat-related deaths, estimated excess mortality > 2000	Katsouyanni et al. (1988)
London, England, 1995	619 excess deaths; 8.9% increase in all-cause mortality and 15.4% in Greater London compared with moving average of 31 days for that period in all age groups	Rooney et al. (1998)

Source: Kovats & Koppe (forthcoming).

14 802 excess deaths (National Institute of Public Health Surveillance, 2003). Similar assessments were carried out in other countries such as Spain and Italy, but the conclusions in these countries were different. Although more than 6000 excess deaths were informally reported during the heat-wave in Spain, only 59 were accepted as being caused by the heat-wave (Table7).

TABLE 7. PROVISIONAL ESTIMATES FOR MORTALITY ATTRIBUTED TO THE HEAT-WAVE IN NOVEMBER, 2003 ACCORDING TO COUNTRY

Country	Heatstroke deaths	Excess deaths (%)[a],all ages	Time period	Method for estimating baseline mortality	Reference
England and Wales	Not reported	2 045 (16%)	4 to 13 August	Average of deaths for same period in years 1998 to 2002 inclusive	Office for National Statistics (2003)
France	Not reported	14 802 (60%)	1 to 20 August	Average of deaths for same period in years 2000 to 2002	National Institute of Public Health Surveillance (2003)
Italy	Not reported	3 134 (15%)	1 June to 15 August	Deaths in same period in 2002	Conti (2003)
Portugal	7	2 099 (26%)	1 June to 31 August	Deaths in same period in 1997–2002	Personal communication from Ministério de Saúde (ministry of health), Portugal, 17 November 2003
Spain	59	Evaluation in progress			Ministry of Health and Consumer Affairs (2003)

[a] *% excess deaths = ([observed – expected]/expected) * 100*

Source: Kovats, Wolf and Menne, 2004

The international literature demonstrates that heat increases death rates from cardiovascular and respiratory disease by placing extra stress on an already stressed system – the precipitating event in a person with chronic disease. Table 8 shows the change in mortality rate from respiratory and cardiovascular diseases per 1 °C increase in temperature above the given threshold.

However, the preliminary information from France shows that all-cause mortality increased in the Central Region of France between 1 and 20 August 2003. Among persons older than 75 years, mortality from heat-related causes such as from heat stroke, dehydration and hyperthermia increased most, and among those younger than 75 years, mortality related to pre-existing mental problems had the biggest increase.

During extreme events, a proportion of deaths are likely to have occurred in very ill people, with the event bringing forward these deaths by a matter of days or weeks. The absolute contribution of this short-term mortality displacement in terms of premature mortality is very difficult to estimate but has implications for estimating the burden of disease.

Heat is likely to significantly affect nonfatal outcomes. However, few time-series studies have quantified the effect of heat exposure on hospital admissions or other morbidity indicators.

TABLE 8. IMPACT OF TEMPERATURE ON CAUSE SPECIFIC MORTALITY:
PERCENTAGE INCREASE IN DEATHS ABOVE THE THRESHOLD TEMPERATURE (95% CONFIDENCE INTERVALS)

Respiratory mortality	Cardiovascular mortality	Temperature threshold (°C)	Population	Reference
5.7% (–2.9, 8.2)	2.9% (–0.4, 7.4)	24	Valencia, Spain	Ballester et al. (1997)
3.11%	1.13%	16.5	The Netherlands	Kunst et al. (1993)
4.7% (2.2, 7.1)	0.8% (–0.4, 2.0)	10	Oslo, Norway	Nafstad et al. (2001)

3.2.3. Who is most vulnerable to heat?

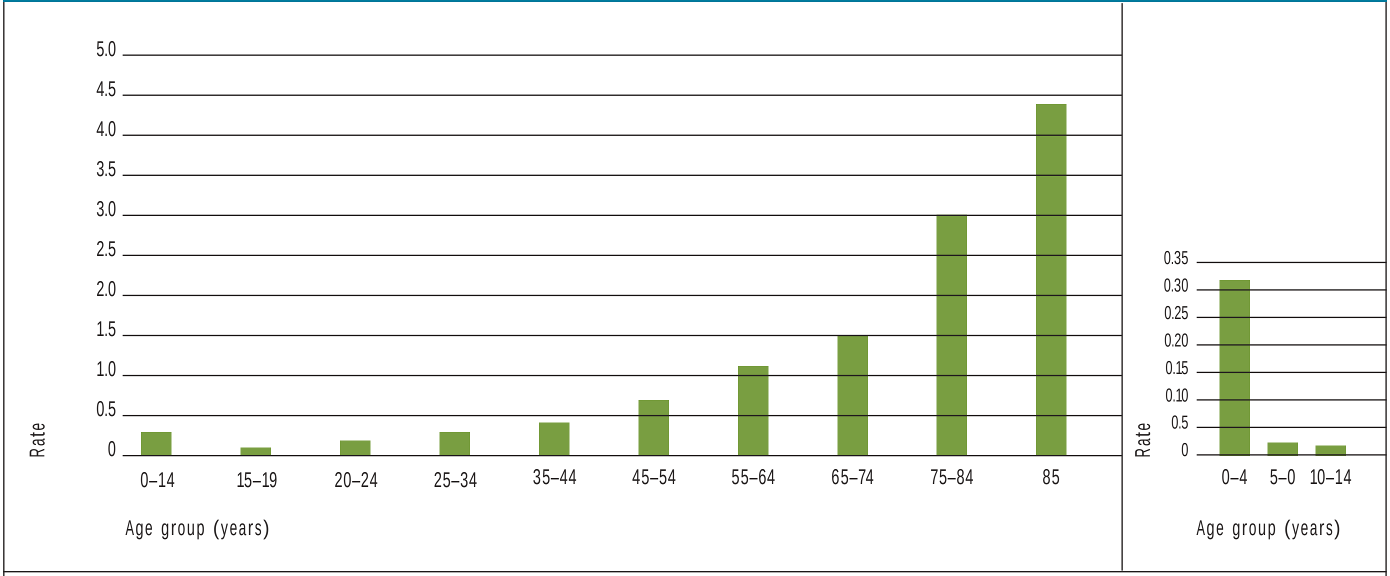
Vulnerability to heat depends on climate factors (such as the frequency of heat-waves) and on individual risk factors, including medical, behavioural and environmental factors. Kilbourne (1992, 1999) has identified as predictive of heat stroke and heat-related death and illnesses:

- being elderly;
- impaired cognition, such as dementia
- pre-existing disease;
- use of certain medications;
- level of hydration;
- living alone;
- housing (such as living in a certain building type or on a higher floor); and
- the presence and use of air-conditioning in the home or residential institution.

A case–control study after the 1995 Chicago heat-wave confirmed that people at increased risk were: already ill; confined to bed; unable to care for themselves; isolated; and without air-conditioning (Semenza et al., 1996). More than 60% of the people who died during the 2003 heat-wave in France died in hospitals, private health care institutions and *maison de retrait* (National Institute of Public Health Surveillance, 2003).

Epidemiological studies indicate that risk in men and women does not differ significantly. Studies, however, vary concerning the age at which vulnerability is shown to increase. Most population-based time–series studies show an effect in adult age groups (Pajares Ortiz et al., 1997), with the effect larger among people 65 years or older versus other ages (Fig. 7). As these studies used predetermined age for

Fig. 7. Average annual rate of heat-related deaths[a] per million population in the United States resulting from weather conditions according to age group, 1979–1997



[a] *Underlying cause of death attributed to excess heat exposure classified according to ICD-9 code E900.0 "due to weather conditions (deaths)".*

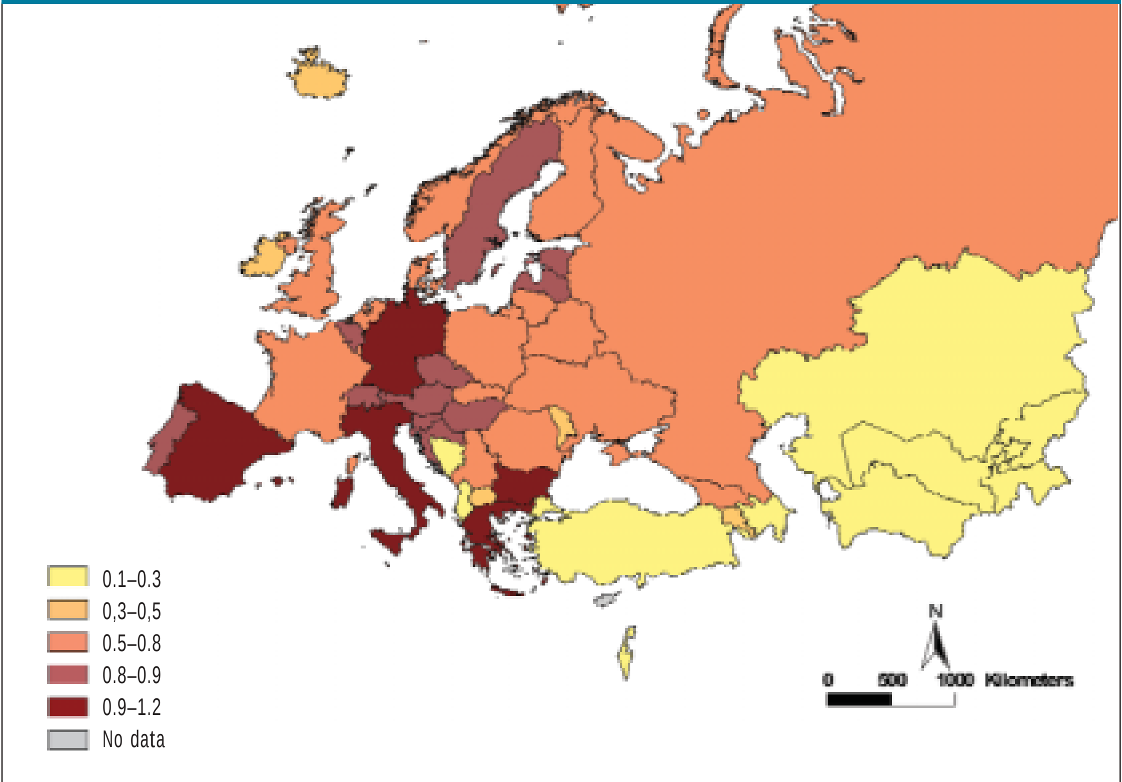
Source: Centers for Disease Control and Prevention (2002).

elderly people, the age at which vulnerability is increased has not been examined in more detail in various populations.Children and infants are at risk of heat-related death (Fig. 7). Overall mortality in this group is very low in industrialized countries. In the United States, less than 4% of all persons dying from heat caused by weather conditions are aged 4 years of age or younger (Centers for Disease Control and Prevention, 2002). Some heat deaths among children are caused by being left in cars on hot days (Donoghue et al., 1997).

People with lower socioeconomic status may be more vulnerable to heat-related mortality because of poorer-quality housing and a lack of air-conditioning. Populations in more deprived areas within a city are also more likely to have other risk factors for heat-related death. Several studies that investigated heat-related mortality rates in different neighbourhoods reveal the importance of socioeconomic factors (Semenza et al., 1996; Smoyer, 1998a, b). The physical and social isolation of elderly people further increases their vulnerability to dying during a heat-wave (Klinenberg, 2002).

Given the vulnerability to heat of the elderly population, it is important to note that life expectancy and the ageing population in Europe are increasing. Germany, Italy and Spain have the highest ageing index, defined as the ratio of the population older than 65 years to that 0–14 years old (Fig. 8).

Fig. 8. Ageing index (the ratio of the population older than 65 years to that 0–14 years old) in countries in the WHO European Region, latest available data for each country



Source: Health for All Database of the WHO Regional Office for Europe

3.2.4. Case study: the health impact of thermal extremes in Madrid, Spain

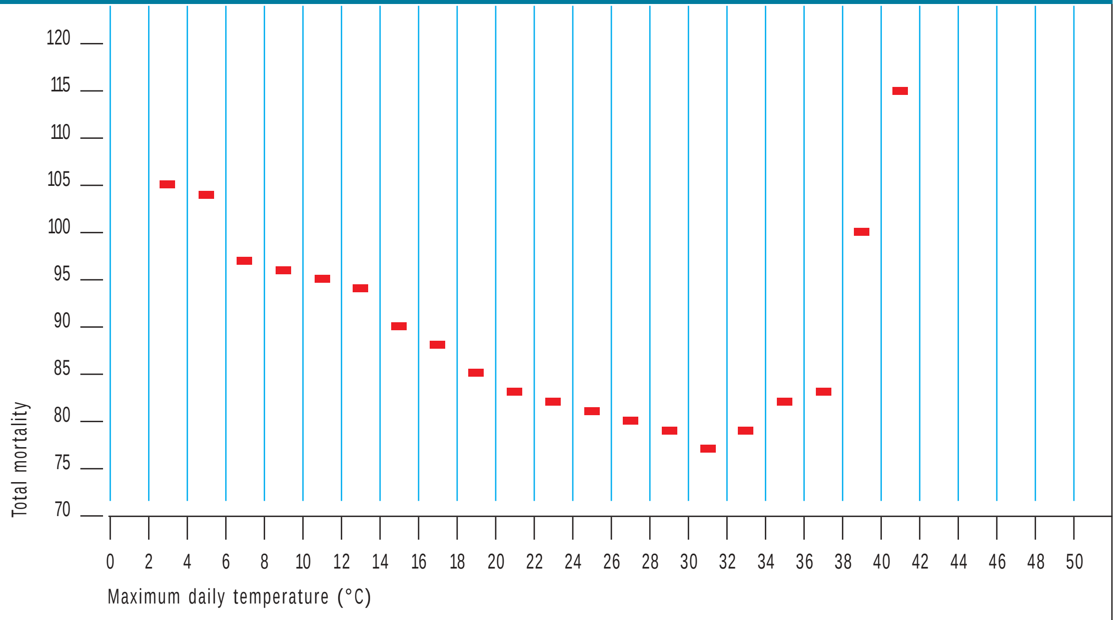
The distribution of all-cause daily mean mortality in Madrid versus daily maximum outdoor temperature from 1986 to 1997 shows the usual V-shaped relationship (Fig. 9), with a minimum at 30.8 °C (comfort temperature). The right branch of the curve has a much steeper slope than the left one. This leads to the conclusion that heat affects mortality more acutely than does cold (Alberdi et al., 1998). The daily maximum temperature at which the slope of the relationship between mortality and temperature becomes steeper is 36.5 °C (Díaz et al., 2002a). Days with maximum temperatures above this threshold are called extremely hot days. The synoptic conditions when extremely hot days occur are in general situations with low pressure and with southerly wind as well as stagnating weather conditions linked to high-pressure conditions (García et al., 2002).

In Madrid the greatest effect of extremely hot days on mortality is on women older than 75 years (28.4% increase per 1 °C above 36.5 °C). The increase in cardiovascular mortality is stronger than the increase from respiratory mortality. For men, the increase in mortality is higher in the age group between 65 to 75 years (14.7% increase per 1 °C over 36.5 °C), but with a higher contribution of mortality from respiratory diseases (Díaz et al., 2002a). Preliminary results for children under 10 years of age did not show any statistical association between the occurrence of extremely hot days and an increase of daily mortality in Madrid (for this period).

For Seville the results were very similar (Díaz et al., 2002b) but the heat stress threshold was 41 °C because the inhabitants of Andalusia's capital are better adapted to thermal stress.

A comparison between Madrid and Lisbon shows that the threshold for the increase in mortality was 33 °C in Lisbon, and the synoptic atmospheric conditions related to extremely hot days were situations with easterly winds and stagnation during high-pressure situations. The impact on mortality associated with extremely hot days was higher for Lisbon, with 31.1% mortality increase per 1 °C increase versus 21.5% in Madrid (García et al., submitted).

Fig. 9. Relationship between all-cause mortality and maximum daily temperature in Madrid, 1986–1997



Source: Díaz & López Santiago (2003).

4. HEAT HEALTH WARNING SYSTEMS

4.1. Methods used by heat health warning systems

4.2. Heat stress indicators

4.3. Public health responses

4.4. Survey of heat health warning systems in Europe

4.5. Case studies

4.6. Recommendations

4.7. Research gaps

4.8. Current research into the development of heat health warning systems

4.1. Methods used by heat health warning systems

One strategy to reduce the current burden of mortality from heat-waves is heat health warning systems that use weather forecasts to predict heat-related effects on human health. The essential components of such systems are identifying weather situations that adversely affect human health, monitoring weather forecasts, implementing mechanisms for issuing warnings when a weather situation that could adversely affect health is forecast and promoting public health activities to prevent heat-related illness and death.

Little is currently known about the effectiveness of these systems in reducing heat-related mortality. Active measures, such as community-based implementation of warning systems to ensure that vulnerable elderly people are reached and that appropriate advice is given, are required. Implementation will vary according to local circumstances, and more evaluation of potential implementation strategies in Europe is needed.

Heat health warning systems are adapted to individual cities and therefore vary widely in the methods used. An effective heat health warning system requires (Auger & Kosatsky, 2002):

- sufficiently reliable heat-wave forecasts for the population of interest (meteorological component);
- robust understanding of the cause-and-effect relationships between the thermal environment and health (epidemiological, statistical and biometeorological component);
- effective response measures to implement within the window of lead-time provided by the warning (public health component); and
- a community that is able to provide the needed infrastructure (public health component).

A heat health warning system first requires identifying weather conditions associated with adverse effects on health (the heat stress indicator). The accuracy of the weather forecast is important. False-positives may result in resources being wasted, and false-negatives represent a missed opportunity for prevention. Both result in a loss of confidence in the forecasts. As the complexity of the indicator increases, this increases the likelihood of an incorrect forecast.

An important factor is the timeliness of the warning in relation to the response. The heat stress indicator should be forecast 12–48 hours in advance to give enough time for the response plan to be implemented. The maximum lead-time for an extreme heat event is about 2 days, as this is the limit for current numerical prediction models in accurately forecasting local weather conditions.

4.2. Heat stress indicators

Many methods are used to identify situations that adversely affect human health. These methods can be grouped into simple and complex approaches. Heat health warning systems should take into account that different populations respond differently to the same weather conditions. The thresholds above which heat stress conditions become sufficiently hazardous to human health to warrant a health warning vary between locations depending on their climate. Further, identifying the threshold is a practical decision and therefore subject to a range of other criteria such as credibility, accuracy (for example, changing the threshold for a warning might improve the sensitivity of a system) and cost (for example, the frequency of triggering a warning influences the cost of the warning system). Thresholds can be derived from biometeorological studies of human comfort under conditions of high temperatures and high humidity. Thresholds can also be derived from statistical analyses of the relationship between weather indices and mortality.

4.2.1. Simple indices

Simple methods are based on thresholds of air temperature (mean, maximum or minimum) or a combination of air temperature and a measure of humidity, sometimes with consideration of how long the thresholds are exceeded. Simple methods are easy to calculate and forecast. The accuracy of forecasts based on simple indices using only one or two parameters is therefore relatively high because uncertainty increases as the numbers of input variables increase. In addition, they are more easily understood by the general public and other stakeholders (such as health service providers).

4.2.1.1. Apparent temperature

The apparent temperature is a measure of relative discomfort from combined heat and high humidity. It was developed by Steadman (1979a, b) and is based on physiological studies of evaporative skin cooling for various combinations of ambient temperature and humidity. The apparent temperature equals the actual air temperature when the dew-point temperature is 14 °C. At higher dew-points, the apparent temperature exceeds the actual temperature and measures the increased physiological heat stress and discomfort associated with humidity that is higher than comfortable. When the dew-point is less than 14 °C, the apparent temperature is less than the actual air temperature and measures the reduced stress and increased comfort associated with lower humidity and greater evaporative skin cooling. It does not account for wind velocity and radiation.

4.2.1.2. Heat index and mean heat index

The United States National Oceanic and Atmospheric Administration issues heat warnings for the entire United States based on the mean heat index. The mean heat index is an average of the heat index from the hottest and coldest times of each day and is therefore more representative of the entire 24-hour period than a single daily maximum value. Forecasts are provided routinely for conditions 3 to 7 days in advance on the web site of the National Oceanic and Atmospheric Administration (Fig. 10).

When severe conditions are forecast within 2 days, the National Oceanic and Atmospheric Administration issues an alert (more severe than a warning) to the public and relevant agencies.

Fig. 10. Three- to seven-day forecast of mean heat index for Dallas, Texas, USA

Mean heat index		Thursday OCT 03 82 °F	Friday OCT 04 82 °F	Saturday OCT 05 76 °F	Sunday OCT 06 70 °F	Monday OCT 07 69 °F
Probability of mean heat index exceeding	100 °F	0%	0%	0%	0%	0%
	95 °F	0%	0%	0%	0%	0%
	90 °F	1%	1%	0%	0%	0%
	85 °F	20%	22%	2%	0%	0%
	80 °F	69%	68%	21%	0%	0%
	75 °F	94%	94%	62%	15%	7%
	70 °F	100%	100%	91%	48%	40%

Source: National Weather Service, National Oceanic and Atmospheric Administration (http://www.hpc.ncep.noaa.gov/heat_index.shtml, accessed 29 October 2003).

4.2.2. Complex indices

Complex indices include all important meteorological and physiological parameters that needed to better describe the physiological heat load: air temperature, water vapour pressure, wind velocity and short- and long-wave radiant fluxes. The complex methods used in heat health warning systems are primarily based on synoptic weather classifications (derived from observed meteorological parameters) and heat budget models (which use meteorological parameters to predict physiological heat load).

4.2.2.1. Indices based on heat budget models

Complete heat budget (energy balance) models take all mechanisms of heat exchange into account and are therefore thermophysiologically relevant to individual exposures and experiences. Most of the approaches refer to a reference environment in which the perception of cold and/or heat would be the same as under the actual conditions.

Fanger’s predicted mean vote (Fanger, 1970) is the heat load that would be required to restore a state of comfort. This is evaluated by Fanger’s comfort equation based on a complete heat budget model of the human body with simple approaches considering skin temperature and sweat rate. The predicted mean vote is still very popular for assessing indoor climate.

Perceived Temperature is used in Germany. The Perceived Temperature is the air temperature of a reference environment in which the perception of heat and/or cold would be the same as under the actual conditions (Staiger et al., 1997). In the reference environment, the wind velocity is reduced to a slight draught, and the mean radiant temperature is equal to the air temperature. Perceived Temperature is based on the comfort equation of Fanger and uses the predicted mean vote correction of Gagge et al. (1986) to account more accurately for latent heat fluxes (evaporation). The thermophysiological assessment is made for a standardized person, referred to as Klima Michel[2], who adapts his clothing between 0.5 and 1.75 clo[3] (baseline clothing in July is 1.0 clo). The assessment procedure is designed for staying outdoors (Jendritzky et al., 2000).

4.2.2.2. Indices based on synoptic approaches

The synoptic approaches are based on the identification of weather types in a given locality. Several studies have identified that specific weather types (air masses) adversely affect mortality (Kalkstein & Davis, 1989). Kalkstein extended this approach to warning systems in the 1980s. Heat health warning systems that use this method have now been set up in several cities in the United States, such as Cincinnati, Dayton, New Orleans, Philadelphia, Phoenix and Washington, DC.

The synoptic procedure classifies days that are considered to be meteorologically homogeneous. This is accomplished by aggregaling days in terms of seven meteorological variables (air temperature, dew point temperature, visibility, total cloud cover, sea-level air pressure, wind speed and wind direction) measured four times daily (Kalkstein, 1991).

[2] *The Klima Michel model is a complete heat budget model of the human body based on the comfort equation by Fanger (1970). Klima Michel is a standardization required to assess the thermal environment. Klima Michel is a man who is 35 years old, is 175 cm tall and weighs 75 kg.*

[3] *Clo units express clothing insulation. 1.0 clo is equivalent to 0.155* $m^2 \cdot K/W$.

4.3. Public health responses

When a threshold is expected to be exceeded or an oppressive air mass is forecast to arrive, a response is required. The warning procedures can be one-, two- or three-tiered. A one-tiered system has a single level of response (yes or no). North America has many two- or three-tiered warning systems. These include a "watch" or an "alert" when a particular level of heat stress occurs or is forecast and an emergency ("warning") stage when the heat stress is projected to exceed the threshold for the active response plan to be put into action. The Philadelphia system, for example, has a three-step warning procedure (Fig. 18). The benefit of this multi-staged early warning approach is that response plans are graded as the confidence in the forecast increases. It provides a maximum 2-day lead-time for intervention activities. This gives public health officials an opportunity to weigh the costs of response actions against the risk posed to the public (National Academy of Sciences, 2000: 87).

There are many different levels of response. The basic (passive) response is to issue a warning of high temperatures (heat stress conditions) through the mass media (television, radio and public web sites).

Public warnings are aimed at the wider community to modify the behaviour of individuals and to increase awareness of the dangers connected with heat exposure in order to reduce heat-related impact. Warnings therefore need to be linked to specific advice on how people recognize the problem and what they should do to protect themselves and others. The United States Centers for Disease Control and Prevention have issued guidelines for reducing heat-related illness (Box 1). These guidelines summarize the general advice that is issued throughout North America, Australia and Europe. Nevertheless, the advice concerning the use of fans might potentially need revision, as in severe heat, fans can add to the level of heat stress, in particular when ambient humidity is high. On the other hand using fans even when temperature exceeds 35 °C can provide comfort, because normally the increase in evaporative

Box 1. Guidelines on preventing and managing heat of the United States Centers for Disease Control and Prevention

- Drink more fluids (nonalcoholic), regardless of your activity level. Don't wait until you're thirsty to drink. Warning: If your doctor generally limits the amount of fluid you drink or has you on water pills, ask him how much you should drink while the weather is hot.
- Don't drink liquids that contain caffeine, alcohol, or large amounts of sugar – these actually cause you to lose more body fluid. Also, avoid very cold drinks, because they can cause stomach cramps.
- Stay indoors and, if at all possible, stay in an air-conditioned place. If your home does not have air-conditioning, go to the shopping mall or public library – even a few hours spent in air-conditioning can help your body stay cooler when you go back into the heat. Call your local health department to see if there are any heat-relief shelters in your area.
- Electric fans may provide comfort, but when the temperature is higher than 35 °C, fans will not prevent heat-related illness. Taking a cool shower or bath or moving to an air-conditioned place is a much better way to cool off.
- Wear lightweight, light-colored, loose-fitting clothing.
- NEVER leave anyone in a closed, parked vehicle.

heat loss is higher than the increase in sensible heat gain. However, intake of liquids must be increased to avoid dehydration. There is no scientific consensus on the efficacy of fans.

A more active approach includes warning providers of health or welfare service and planned intervention activities being in place. The Philadelphia intervention schedule is one example (Kalkstein, 2001).

- The "buddy" system is promoted: mass-media announcements encourage friends, relatives, neighbours, and other volunteers to make daily visits to elderly people during hot weather.
- The Heatline is activated, which provides information and counselling to the general public on avoiding heat stress, by telephone.
- Department of Health field teams make home visits to people requiring more attention than can be provided over the Heatline.
- Nursing and personal care boarding home interventions: when a warning is issued, these facilities are informed of the high-risk heat situation.
- Utility service suspension is halted during warm periods.
- Hospital emergency staffing is increased.
- Daytime outreach to homeless people is carried out.

Intervention plans should be best suited to local needs, through coordination between the local health agencies and meteorological officials (Cegnar & Kalkstein, 2000). A comprehensive warning system should involve multiple agencies, such as: city managers, public health and social services workers and emergency medical officers.

- Although anyone at any time can suffer from heat-related illness, some people are at greater risk than others. Check regularly on: infants and young children, people aged 65 or older, people who have a mental illness and those who are physically ill, especially with heart disease or high blood pressure.
- Visit adults at risk at least twice a day and closely watch them for signs of heat exhaustion or heat stroke. Infants and young children, of course, need much more frequent watching.

If you must be out in the heat

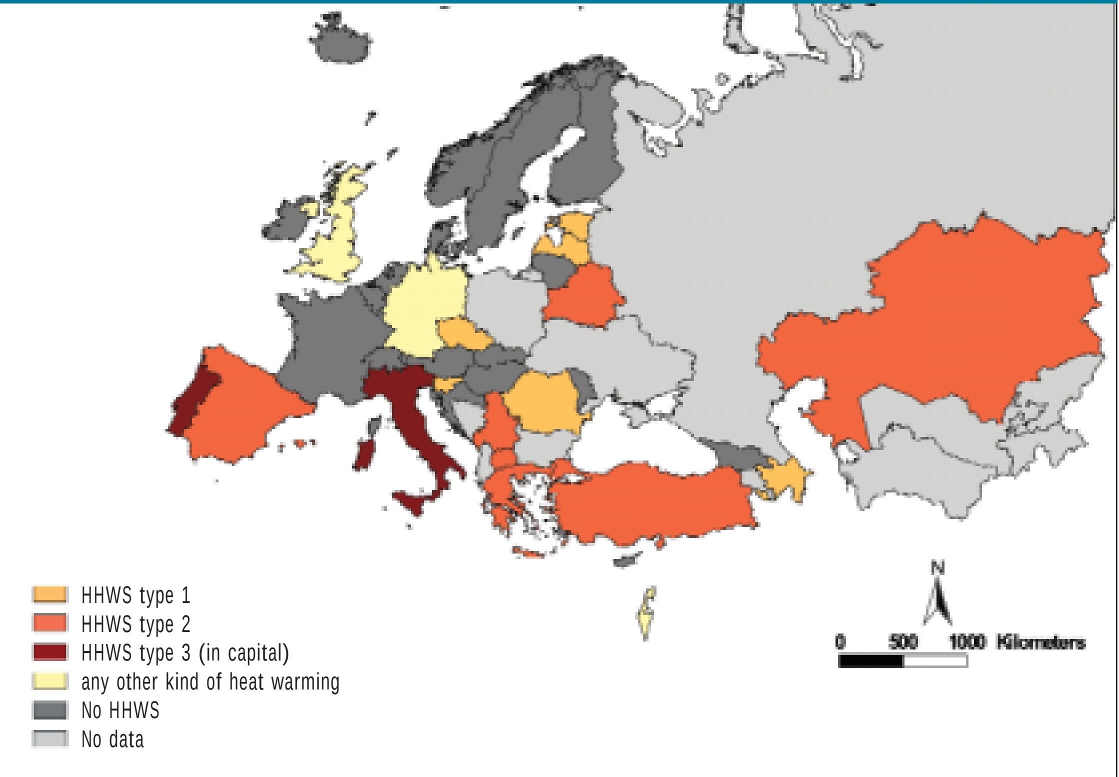
- Limit your outdoor activity to morning and evening hours.
- Cut down on exercise. If you must exercise, drink two to four glasses of cool, nonalcoholic fluids each hour. A sports beverage can replace the salt and minerals you lose in sweat. Warning: if you are on a low-salt diet, talk with your doctor before drinking a sports beverage. Remember the warning in the first "tip" (above), too.
- Try to rest often in shady areas.
- Protect yourself from the sun by wearing a wide-brimmed hat (also keeps you cooler) and sunglasses and by putting on sunscreen of SPF 15 or higher (the most effective products say "broad spectrum" or "UVA/UVB protection" on their labels).

4.4. Survey of heat health warning systems in Europe

National meteorological services in Europe were surveyed by questionnaire to identify heat health warning systems and to evaluate their benefits. The goal of this questionnaire was to understand whether the national services define heat-waves, whether they have heat warning systems and how they work. Questionnaires (Annex 2) were sent to 45 countries in the WHO European Region.

Fifteen countries declared that they had a heat health warning system (Fig. 11, Annex 3). In Germany, warnings are given only to the health resorts in the southwestern part of the country. In Portugal the system only covers the district of Lisbon and in Italy only the city of Rome.

Fig. 11. Heat health warning systems (HHWSs) in Europe.



4.4.1. Criteria for initiating heat warnings

All countries except Germany use simple weather indices based on temperature and/or humidity to forecast the effects of weather on health (Table 9). Eight countries use simple temperature thresholds (Azerbaijan, Belarus, Czech Republic, Greece, Latvia, Malta, Serbia and Montenegro and Spain). Three use a combination of temperature and relative humidity (Romania, The former Yugoslav Republic of

TABLE 9. THRESHOLD CRITERIA FOR RELEASING HOT WEATHER WARNINGS

Country	Criteria for releasing the warning	Reference temperature
Temperature threshold		
Azerbaijan	40 °C in more than 30% of the territory–42 °C in one region	Not specified
Belarus	35 °C	“Air temperature”
Czech Republic	29 °C medium heat stress; 33 °C high heat stress	“Maximum air temperature”
Greece	38 °C	“Maximum air temperature for 3 consecutive days”
Latvia	33 °C	“Air temperature”
Malta	40 °C	“Maximum air temperature”
Portugal (district of Lisbon)	Daily maximum temperature > 32 °C and other parameters derived from local temperature–mortality relationship	Maximum temperature
Serbia and Montenegro	35 °C–20 °C	Maximum air temperature Minimum air temperature
Spain		Maximum temperature
Temperature and humidity threshold		
Romania	Temperature humidity index: (ITU) ≥ 80 $ITU = T(^\circ F) - (0.55 - 0.55{*}RH/100){*}(T(^\circ F) - 58)$ RH: relative humidity	
The former Yugoslav Republic of Macedonia	Increasing heat index (apparent temperature)	
Turkey	Temperature > 27 °C and relative humidity > 40%	
Complex index threshold		
Southwestern Germany	Maximum perceived temperature > 26 °C	

Macedonia and Turkey), and The former Yugoslav Republic of Macedonia uses the mean heat index (see above). Greece, Latvia and Romania use their definition of a heat-wave as the condition for releasing hot weather warnings.

In southwestern Germany, warnings are given to health resorts when the forecast perceived temperature exceeds a given threshold (maximum perceived temperature greater than 26 °C). Perceived Temperature is a complex indicator derived from a complete heat budget model.

The threshold criteria for the Lisbon heat health warning system is 32 °C. The system was initiated during summer 1999. The basis of this system is the ÍCARO index developed at the National Institute of Health. The model uses a 3-day forecast value of maximum temperature to predict heat-related deaths. The model output is sent to the National Health Directorate and the Directorate of Civil Protection (see below).

In general, warnings are ended when the criteria for releasing the warning are no longer met.

4.4.2. Target population

Warnings are given on different scales. Warnings on the national scale are given in Azerbaijan, Belarus, Latvia, Serbia and Montenegro and Turkey. Warning the whole country makes sense in small countries with homogeneous weather conditions. Belarus and Latvia have relatively flat topography. However, a single warning may not be appropriate for Turkey, which has a heterogeneous climate. The Czech Republic, Israel, Kazakhstan, Slovenia and Spain provide subnational-scale warnings. The remaining heat warning systems (5 of 15) target the city level.

4.4.3. Lead-times

Table 10 shows the lead-time for the warning. The warning is transmitted to the public between 1 and 3 days in advance by mass media. Israel has a three-step warning procedure, with the first warning given 2–3 days in advance, a second warning 1 day in advance and a third warning 12 hours before the expected event. In many countries the health or civil protection authorities are informed separately.

4.4.4. Intervention plans

In most countries, the heat health warning systems did not include any intervention apart from issuing a passive warning to the general public and to the local public health agencies. In four countries, warnings were issued solely through the mass media. In two countries only the health agencies were informed.

TABLE 10. MAXIMUM LEAD-TIME FOR THE HEAT WARNING IN THE EUROPEAN COUNTRIES SURVEYED

Lead-time for the warning	Countries
1 day or less	Czech Republic, Kazakhstan, Latvia, Malta, Serbia and Montenegro, Slovenia and Turkey
1–2 days	Belarus, southwestern Germany and Spain
2–3 days	Israel, Greece and Portugal (district of Lisbon)

In Romania, the working day may be shortened or divided into two parts (until 11.00 and from 17.00 on). The interventions in Romania focus on protecting workers. Serbia and Montenegro has no unique intervention plan but intervention options include supplying citizens with additional water and telling them to protect themselves from ultraviolet radiation, implemented by public and municipal services.

4.4.5. Target groups and aim of the warnings

The warnings target the general public in all countries that have heat health warning systems. In Belarus and Romania, warnings target workers and employers.

About 20 health resorts in southwestern Germany are warned. Many people visiting these health resorts are recovering from a serious illness or have chronic cardiovascular disease.

In Azerbaijan, Israel, Kazakhstan and Latvia, the warnings also target fire departments to prevent forest fires. The warning in Serbia and Montenegro, apart from its focus on human health, has another focus on agriculture. In Spain, the warnings aim to "prevent disasters related to very hot temperatures"

4.5. Case studies

4.5.1. Heat health warning system in Rome, Italy

4.5.1.1. Introduction

WHO, WMO and the United Nations Environment Programme have collaborated on a project to develop and implement a heat health warning system for Rome as part of a showcase project (Cegnar & Kalkstein, 2000; Kalkstein, 2000). The Rome system was developed at the University of Delaware in cooperation with the Lazio Health Authority and the Italian Meteorological Service. The Department of Epidemiology is responsible for running the system. The Italian Meteorological Service provides 72-hour forecasts for five meteorological variables. The system was run in experimental mode in the summers of 2000 and 2001. The active phase of the Rome heat health warning system started in summer 2002.

4.5.1.2. Methods

The Rome heat health warning system is based on a synoptic heat stress indicator. The first step was to describe using recent historic data the current relationship between mortality and an extended set of meteorological parameters in the Rome population (Kalkstein, 2000). Daily mortality data were obtained for a 10-year period from 1987 to 1996. Weather conditions were classified into eight types. The mean effect of each of these weather types on daily mortality (all causes) was estimated. The greatest effects on mortality were among people 65 years or older and among women (Cegnar & Kalkstein, 2000). Two types of weather had a statistically significantly higher mean daily mortality among people 65 years or older:

- dry tropical (frequency 7.0%)
- moist tropical plus (frequency 4.3%).

Dry tropical and moist tropical plus are associated with 5–7 excess deaths per day. Box 2 shows the algorithms for excess mortality when the dry tropical or moist tropical plus air masses are forecast for the next day. For moist tropical plus air masses, the minimum temperatures are not important and the total heat load is a function of cooling degree hours.

The Italian Meteorological Service provides 72-hour forecasts with all the meteorological variables necessary to identify whether a "dangerous" air mass is likely to occur within days. The forecast data is fed into a password-protected web site available to Lazio health officials.

The warning procedure consists of three steps: attention, alarm and emergency. The attention warning is given if an offensive weather type is expected within the following 2 days. The alarm is given if the weather type is expected within the next 24–48 hours and the number of excess death is estimated at two or more. If the alarm situation persists for more than 2 days, an emergency is declared (Fig. 12). The risk levels are not based on the numbers of excess deaths predicted because the system tends to underestimate the negative health effects in terms of mortality.

4.5.1.3. Interventions

The Department of Epidemiology of the Lazio Health Authority releases a daily bulletin between May 15 and September 15 (Fig. 13). In addition to the state of the warning, the bulletin recommends how to cope with heat. The bulletin is published daily on the web site of the Department for Social Policies and

Box 2. Algorithm for excess mortality in Rome for dry tropical (DT) and moist tropical plus (MT+) air masses

DT air mass[a]

No. of deaths = –45.92 – 0.08*TS + 2.05*DIR + 1.61*AT_{min+1} + 0.75*AT_{min+2}

$R^2 = 0.46$

TS	time of season (days since 14 May)
DIR	consecutive days of oppressive air mass (DT or MT+)
AT_{min+1}	minimum apparent temperature forecast for tomorrow
AT_{min+2}	minimum apparent temperature forecast for the day after tomorrow
AT	apparent temperature derived from temperature, humidity and wind speed

MT+ air mass[a]

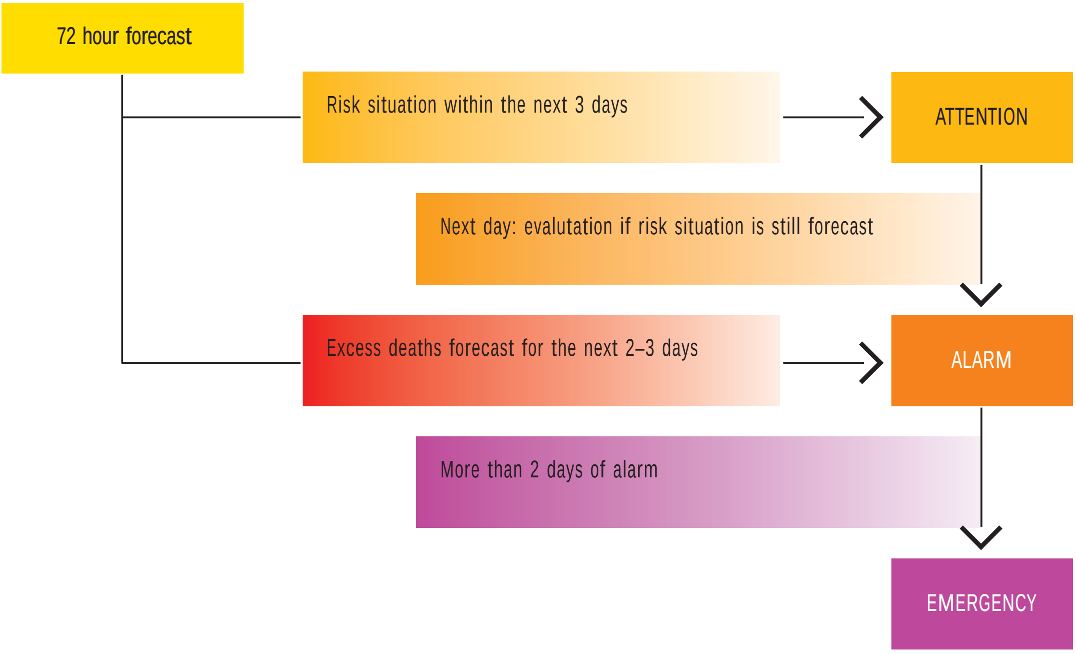
No. of deaths: –4.84 – 0.13*TS + 0.82*CH_{+1}

$R^2 = 0.26$

CH_{+1}: cooling hours (hours * degrees above 20 °C) forecast for tomorrow

[a] *Other variables included in the regression analysis were yesterday's, today's and tomorrow's maximum temperatures, minimum temperature, cloud cover, afternoon dew point, cooling degree hours and maximum apparent temperature*

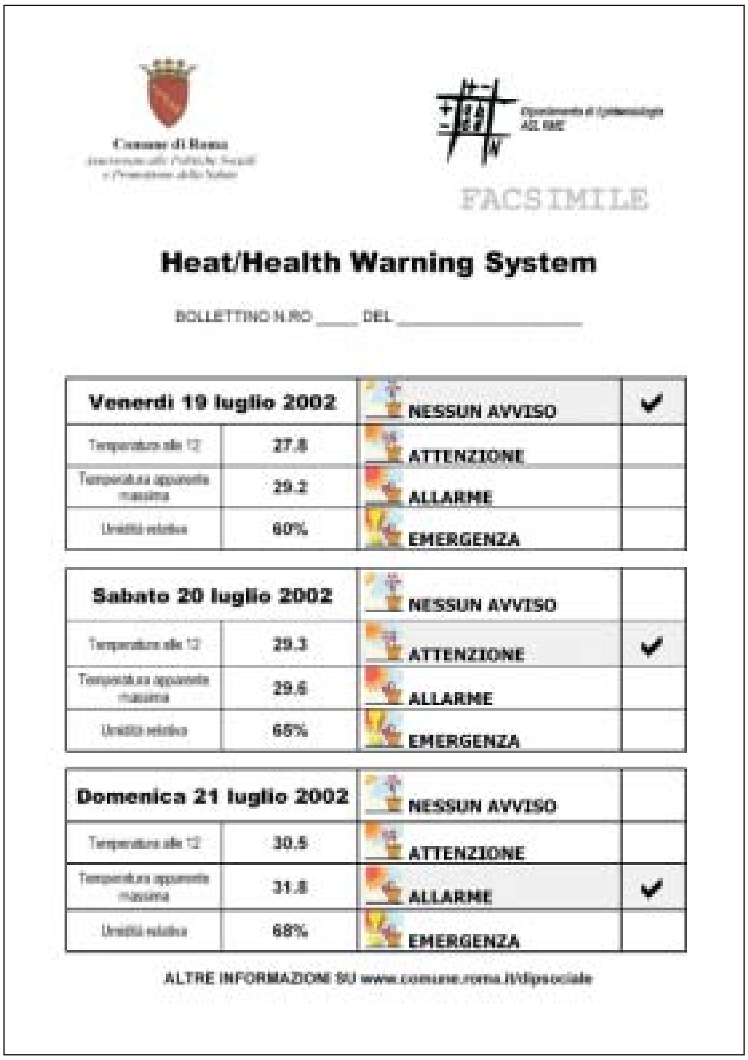
Fig. 12. Flow chart of the heat warning procedure in Rome



Sources: Comune di Roma http://www.comune.roma.it/dipsociale/comunicati_stampa/com_warning_system_2003.htm (accessed 29 October 2003) and PHEWE (2003).

Health Promotion. In case of an attention, alert or emergency, the bulletin is sent to the Operative Centre of the Municipality of Rome. The intervention plan is put into action through the local municipality. This plan consists of alerting the different subjects involved in the imminent risk and providing specific advice for reducing heat-related illnesses (PHEWE, 2003).

Fig. 13. Bulletin of the Rome heat health warning system



Comune di Roma

FACSIMILE

Heat/Health Warning System

BOLLETTINO N.RO _____ DEL ____________________

Venerdi 19 luglio 2002		NESSUN AVVISO	✓
Temperatura alle 12	27.8	ATTENZIONE	
Temperatura apparente massima	29.2	ALLARME	
Umidità relativa	60%	EMERGENZA	

Sabato 20 luglio 2002		NESSUN AVVISO	
Temperatura alle 12	29.3	ATTENZIONE	✓
Temperatura apparente massima	29.6	ALLARME	
Umidità relativa	68%	EMERGENZA	

Domenica 21 luglio 2002		NESSUN AVVISO	
Temperatura alle 12	30.5	ATTENZIONE	
Temperatura apparente massima	31.8	ALLARME	✓
Umidità relativa	68%	EMERGENZA	

ALTRE INFORMAZIONI SU www.comune.roma.it/dipsociale

Source: http://www.comune.roma.it/dipsociale/Downloads/Schede_estate_anziani/scheda%20heat%20warning%20system.pdf, (accessed 29 October 2003).

The target groups for this bulletin are general practitioners, local health care agencies, hospitals and health resorts, homes for elderly people, social institutions that take care of elderly people, the mass media and registered individuals.

The guidelines for behaviour in heat-waves were developed in collaboration with the Italian Association of General Practitioners.

The heat health warning system is also connected with a system of tele-assistance that connects the homes of registered individuals with an operative centre (active 24 hours per day). This tele-assistance system provides various types of assistance such as counselling, food and drug deliveries, emergency calls, regular check-in calls and activation of assistance networks (social services and volunteers). The first step was to integrate the heat health warning system intervention activities with the tele-assistance programme, using already existing networks (PHEWE, 2003).

The interventions are aimed at elderly people and other susceptible people, such as people suffering from chronic diseases. To reach these target groups, the following public and private institutions and organizations were identified to act as mediators between the heat health warning system and the population:

- Italian Association of General Practitioners
- tele-assistance service
- public and private nursing homes
- local health authorities and public hospitals
- public and private volunteer organizations
- private hospitals.

4.4.5.1. Evaluation of the system

Fig. 14 compares the mortality predicted by the heat health warning system with that observed in 2001. Apart from the warnings made between July 25 and August 6, excess mortality was underestimated. One reason for this might be that the model is run with meteorological data from the airport, which is situated more than 20 km from the city centre and near the sea. The temperatures forecast for the airport are therefore expected to be lower than the temperatures in the city centre (urban heat island). However, the model was calibrated with meteorological data from the airport. So if there was no change in the relationship between urban temperatures and airport temperatures, this fact should not lead to an underestimation of excess mortality. However, for summer 2003 corrections were introduced to the raw forecast meteorological data to better represent the local weather conditions in Rome. Temperatures were corrected based on the differences between the observed and predicted values of the previous 24 hours and in relation to the model's predictive bias (PHEWE, 2003).

Alarms were called on 10% of the days in 2000, 22% in 2001 and 19% in 2002.

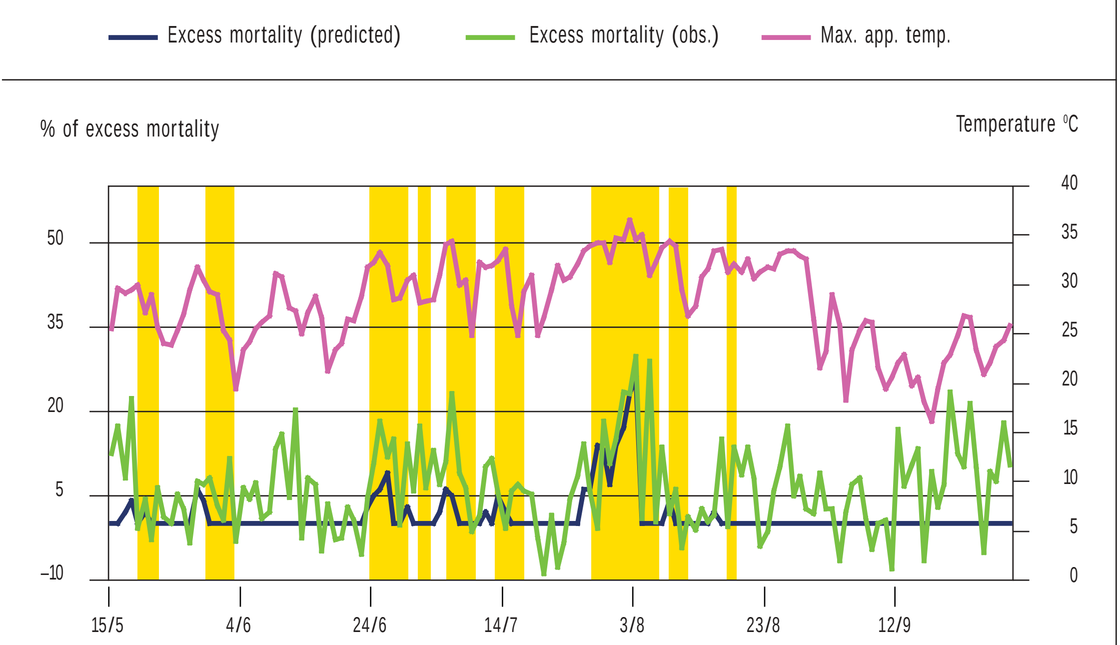
Evaluating the system requires an a priori definition of a heat-wave based on meteorological observations. The definition used in Rome is based on a combination of maximum apparent temperature threshold, duration, and change in the apparent temperature.

Periods defined with oppressive air masses associated with excess deaths identified by the system correspond to the longest heat-waves observed, whereas the heat health warning system did not depict short-lived events, even those events produced excess deaths. Incorporating heat-waves and apparent temperatures into the heat health warning system in future years could help to increase the accuracy and the sensitivity of the model (PHEWE, 2003).

To evaluate the performance of the system, the following indicators have been calculated:

- sensitivity (ability to detect true alarms): number of days with true alarms/number of days with excess deaths;
- specificity (ability to detect true non-alarms): number of days with true non-alarms/number of days without excess deaths; and
- positive predicted value: total days with true alarms/total days with alarms.

Fig. 14. Alarms called by the heat health warning system in Rome in 2001 (yellow bars) compared with observed mortality and maximum apparent temperature



Source: Michelozzi (2003).

Excess mortality was calculated by subtracting the 11-day running mean from the daily value of mortality. The system shows high specificity (true non-alarms) but low sensitivity (few true alarms predicted). Sensitivity increases as the observed mortality excess increases: at alarm level from a sensitivity of 32% to 68% when excess mortality increases from 20% to 50% (PHEWE, 2003). The positive predicted value is relatively high (0.86), which means few false positives were called between 2000 and 2002.

The results highlight the need to improve the performance of the system to increase its sensitivity. The system performed more accurately for events characterized by long periods of oppressive air masses and large numbers of excess deaths observed but generally underestimates the actual number of excess deaths. The system achieved a higher predictive level by including the days defined in the model as attention level, where an oppressive air mass was predicted for the third day, and not necessarily confirmed in the subsequent forecast. It also became apparent that the definition of alarm and attention levels used was not effective. For 2003, a new classification was developed based solely on predicting excess deaths and oppressive air masses. The highest level of warning (emergency) also takes into account the persistence of an offensive air mass. The emergency level is called only when an alarm is predicted for more than two consecutive days (PHEWE, 2003).

In conclusion, a good heat health warning system can reduce mortality, but the effectiveness of the intervention measures must be formally evaluated. The effectiveness of the interventions will be evaluated when the system in Rome is in full operation.

4.5.2. The Lisbon heat health warning system – the ÍCARO Project

4.5.2.1. Introduction

The ÍCARO Project was set up as a response to a severe heat-wave in 1981. On 15 June 1981 Lisbon was the hottest capital in the world. When maximum temperatures reached 43 °C, the number of heat-related deaths was 63 and the number of excess deaths 1906.

4.5.2.2. Methods

The ÍCARO Project defines a heat-wave by means of a temperature threshold of 32 °C combined with a minimum duration of 2 days. This definition is similar to a definition used in the United States: 90 °F (32.2 °C) and a minimum duration of 2 days (Paixão & Nogueira, 2002). For the current implemented model, the temperature threshold is constant over the summer season (1 May – 30 September), although the awareness exists that sensitivity weakens in late summer (Nogueira et al., 1999). A simplified statistical model is used for the surveillance system, reflecting the period in which the threshold is exceeded (Fig. 15) (Nunes & Castro, 1997).

Fig. 15. Algorithm of the Lisbon heat health warning system

Forecasting model for excess deaths related to heat waves

$$Y_t = C + \alpha \ ATO\ (32)_{t-1} + \eta_t$$

Nunes e Canto e Castro (1997)

Y_t Number of deaths on day *t*

η_t Stationary process ARIMA (1,1)

Accumulated Thermic Overcharge (over threshold τ) until the day *t*

$$ATO\ (\tau)_t = C - OND\ (\tau)_t \times Ex\ (\tau)_t$$

Number of consecutive days that the maximum temperature is over τ until the day *t*.

Excess of the maximum temperature over τ, on the day *t*.

Source: Nogueira & Paixão (2003).

The ÍCARO Index is calculated as follows:

(Number of expected deaths with the effect of heat (Yt)/number of expected deaths without the effect of heat) –1

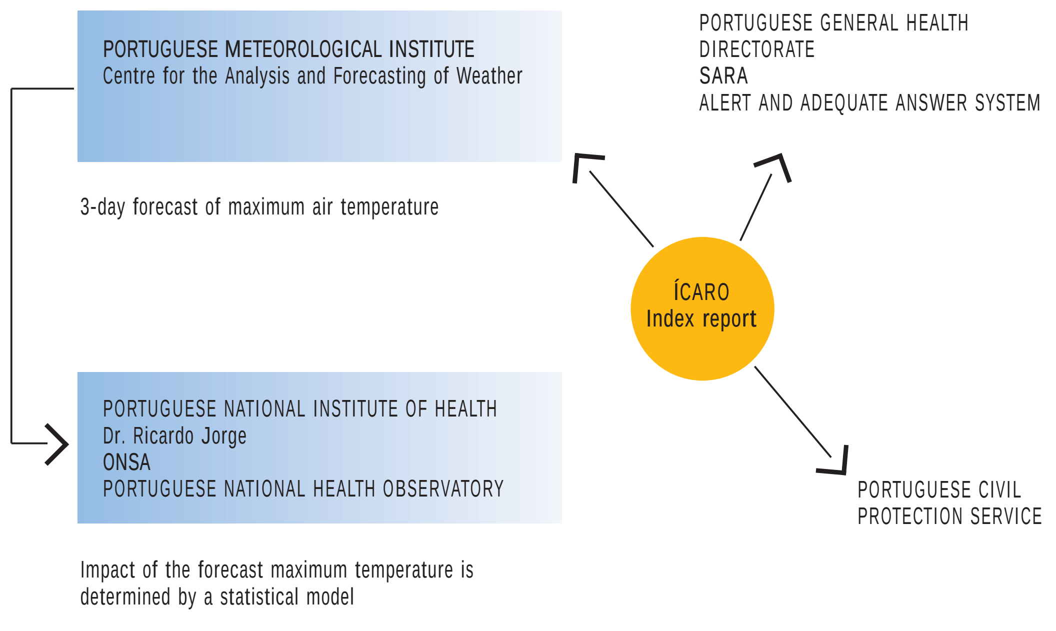
The "number of expected deaths without the effect of heat" is the average summer (here including from 1 May to 31 August) mortality without heat-wave days (Paixão & Nogueira, 2002). An ÍCARO Index of 0 therefore means that heat has no effect on mortality and an ÍCARO Index of 1 that the mortality risk from heat is doubled.

4.5.2.3. Interventions

The partnership supporting the heat health surveillance system is an integrated functional set of institutions interested in health and saving lives: the Portuguese National Institute of Health, the Portuguese Meteorological Institute, the Portuguese General Health Directorate and the Portuguese Civil Protection Service (Fig. 16) (Garcia et al., 1999).

The ÍCARO Index has four different levels with different effects on excess mortality (Table 11). The first and second levels of the ÍCARO Index (< 0.31) do not require any special intervention. If the ÍCARO Index reaches the third level, an announcement is made that a heat-wave may arrive within the next few days. The alert triggers intervention measures that are within the responsibility of the Portuguese General Health Directorate and the Portuguese Civil Protection Service. For instance, the public health emergency telephone line is used as a heatline and reinforced with nursing personnel when there is a heat-wave warning.

Fig. 16. Flow chart of the Lisbon heat health surveillance system



Source: Nogueira (2003).

4.5.2.4. Evaluation

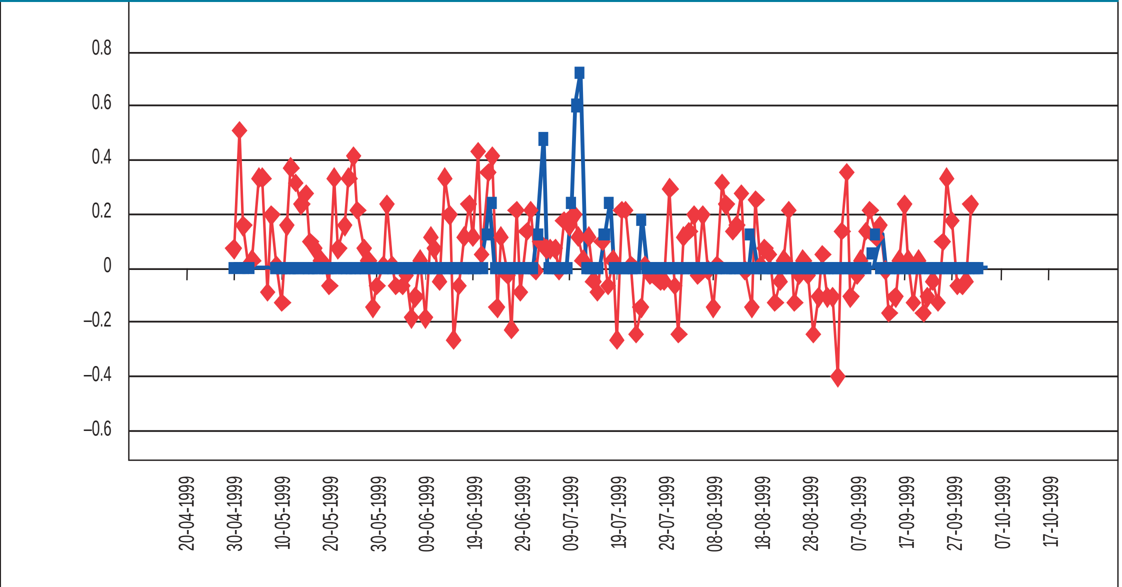
The surveillance system has been evaluated comparing predicted and observed mortality for the summers of 1999 and 2000 (Nogueira, 2000a, b) (Fig. 17). Mortality was well predicted for the first heat-wave in summer 1999. However, some discrepancy still remains between observed and predicted values for the heat-waves. wich followed. Even when the threshold for the ÍCARO Project was not exceeded, relatively high indices were observed. This was especially the case in early summer, which leads to the conclusion that a moving threshold for the system might be more suitable than the fixed threshold of 32 °C.

TABLE 11. THRESHOLDS OF THE LOWER LIMIT OF THE 95% INTERVAL OF THE ÍCARO INDEX

Threshold	**Effect on mortality**
< –0.31	No effect on mortality
–0.31–0.31	No significant effect on mortality
0.31–0.93	Effect on mortality is probable
> 0.93	Heat-wave alert

Source: Noguiera et al. (1999).

Fig. 17. Comparison between the observed ÍCARO Index (red line) and predicted ÍCARO Index (blue line), summer 1999



Source: Nogueira & Paixão (2003).

4.5.3. Philadelphia Hot Weather Health Watch/Warning System

4.5.3.1. Introduction

Philadelphia has experienced several major heat-waves, most recently in 1995 and 1999. The Philadelphia Hot Weather Health Watch/Warning System was initiated in 1995 and was one of the first systems to be operational based on synoptic indices of heat stress (Kalkstein et al., 1996; Sheridan & Kalkstein, 1998).

The method that identifies dangerous situations is the same as for the Rome system. The Philadelphia system uses the maximum apparent temperature to predict the number of excess deaths attributable to the hot weather on a given day.

4.5.3.2. Methods

The Philadelphia system is a three-tiered system (Fig. 18). A watch, an alert and then a warning are issued depending on the weather conditions forecast. In the final tier, there are three levels of health warnings, and these depend on the number of excess deaths predicted by the model.

Web-based forecast tools are employed within these systems for ease of communication across varied agencies. Initial forecasting, up to 48 to 60 hours in advance, proceeds automatically via electronically transmitted digital forecast information. Meteorologists may then update expected conditions at any time, leading to a re-evaluation of the oppressiveness of the forecast.

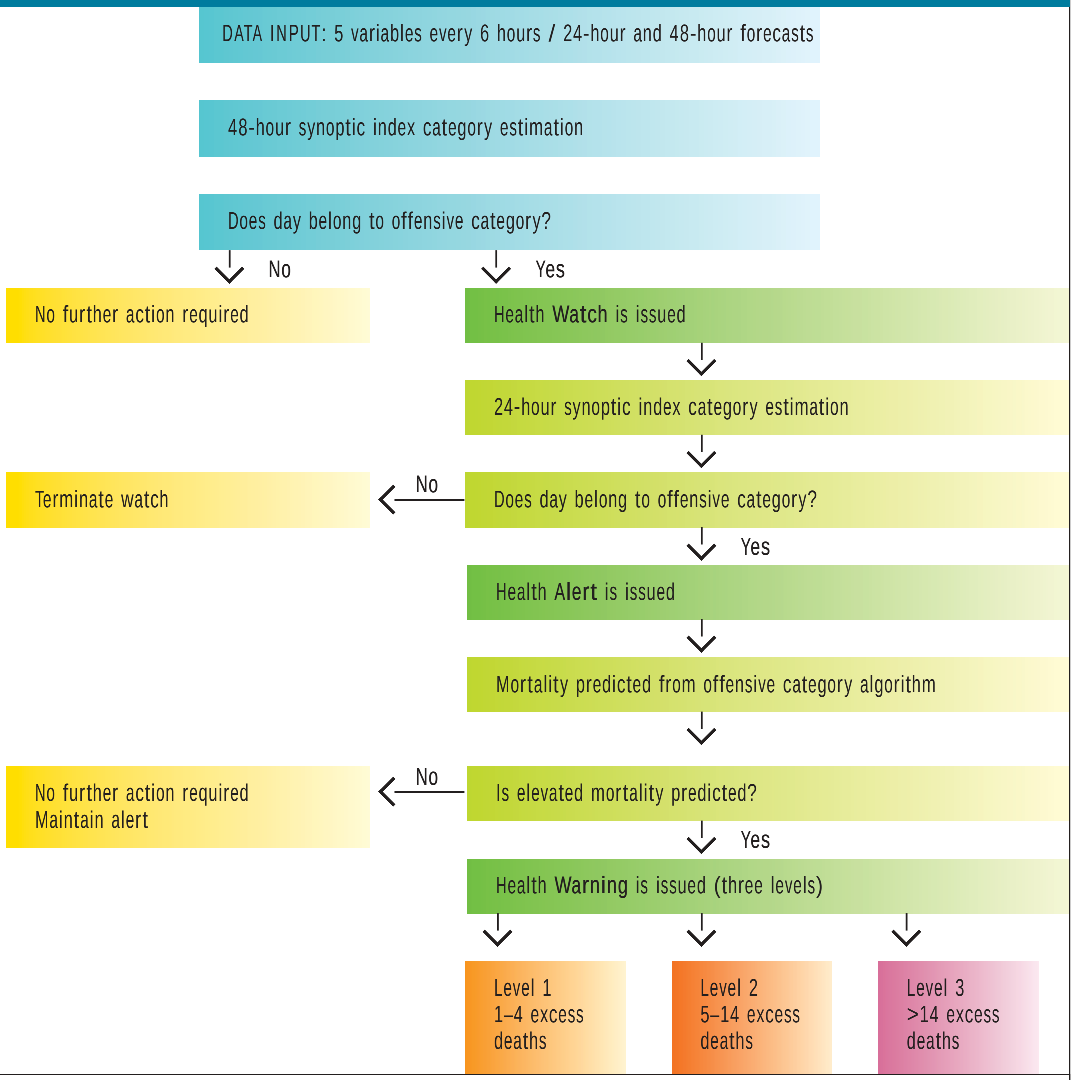
4.5.3.3. Interventions

Philadelphia has a very elaborated set of heat health intervention activities that become effective anytime the United States National Weather Service calls a heat warning. The Philadelphia intervention plan is unique because of its coordination between different agencies, both public and private. The Philadelphia Department of Public Health maintains very close relationships with the Philadelphia Corporation for Aging, a private organization that plays a major role when a warning is called (Kalkstein, 2002).

The following intervention activities are in place in Philadelphia.

- The mass media publicize both the weather conditions and information on how to avoid heat-related illnesses.
- The mass media encourage friends, relatives and neighbours to make daily visits to elderly people.
- The city identifies block captains. They recruit citizens who have agreed to assist neighbours. The city trains block captains, who are sent information to assist them in dealing with heat problems in the neighbourhood.
- A Heatline is operated in conjunction with the Philadelphia Corporation for Aging to provide information and counselling. The Heatline number is publicized by the mass media and also on a high-visibility display seen over a large area of the Philadelphia city centre.
- Department of Public Health mobile field teams make home visits to people requiring more attention than can be provided over the Heatline but still not requiring emergency intervention.
- The Department of Public Health contacts nursing homes and other facilities to inform them of the high-risk heat situation and to offer advice on protecting residents.

Fig. 18. Schematic of the warning procedure of the three-tiered heat health warning system in Philadelphia



Source: World Meteorological Organization (1999).

- The utility company and water department halt service suspensions during warning periods.
- The Fire Department Emergency Medical Service increases staffing.
- There is daytime outreach for homeless people.
- The Department of Public Health has the capability to move people at high risk out of dangerous living situations to an air-conditioned (overnight) shelter facility.
- Senior centres extend their hours of operation.

During summer 2002, the Heatline was called over 2300 times. In about 25% of the cases, the person calling in was referred to a nurse, who gave the individual more specific information to lessen the caller's stress. A few cases (64) were severe enough to dispatch a mobile team to the home of the distressed person (Kalkstein, 2002).

4.5.3.4. Evaluation of the system

Philadelphia's system is probably the most advanced anywhere in the world. Most studies evaluating systems have therefore addressed the Philadelphia system.

Kalkstein et al. (1996) described the first year the system was running (1995), which fortuitously was also the year of a major heat-wave. The algorithm predicted a total of 163 excess deaths due to oppressive air masses occurring on 15 days. According to the criteria, level 2 and level 3 warnings should have been issued on 12 and 3 days, respectively. The Department of Public Health issued actual warnings on only 9 of these days because the National Weather Service did not concur.

The number of reported deaths caused by heat was 72 for the whole year, and 32 heat deaths occurred during the particular heat episodes of 13–15 July and 2–5 August when warnings were issued. Thus, the system did forecast deaths at times when they actually did occur (during the period of highest temperatures). These outcomes cannot be compared directly. The Philadelphia model predicts excess deaths (all ages and all causes) and not certified heat deaths. The excess deaths during a heat-wave always exceed the certified heat-related deaths. Deaths were predicted for the Greater Philadelphia area, and the certified heat deaths were only from the city of Philadelphia. Clearly, the systems did not prevent all the heat deaths that occurred. There is no way of estimating whether more heat deaths may have occurred in the absence of the warning.

The Philadelphia system over-predicted excess mortality by a considerable margin in early and mid-August in 1995 (Kalkstein et al., 1996). One reason may be that the late-season episodes have fewer effects because of acclimatization or the loss of susceptible people. Alternatively, the system may have been effective in reducing mortality.

4.5.3.5. Evaluation of the interventions

Teisberg et al. (in press) evaluated the Philadelphia system in more detail. They calculated the costs of the Philadelphia system and the benefits in reducing mortality among people 65 years or older, the age group assumed to be at highest risk. The value of a statistical life was calculated as follows. First, the value to relevant individuals of small reductions in their individual mortality risk was estimated. Second, these values were summed over the affected population. Third, the mortality risk over the population was summed. The value of a statistical life is the sum the population is willing to pay divided by the expected number of deaths in the population. Its unit is money per life saved.

One problem of this method is whether the value of a statistical life is lower for older people or for people with health problems. Both groups of people have a relatively high risk of dying during a heat-wave. As cited in Teisberg et al. (in press), older people value reducing mortality less highly but not people with serious illness. For this reason, the authors estimate the value of a statistical life to be about US$ 4 million per life saved by the Philadelphia system (versus about US$ 6 million among people younger than 65 years).

Excess mortality among people 65 years of age and older was defined as the reported mortality minus the mortality predicted by a historical trend line developed over the period 1964–1988. Based on linear regression analysis, Teisberg et al. (in press) found out that issuing a warning during a heat-wave saves about 2.6 lives for each warning day and for 3 days after the warning ended. Two variables were convincingly associated with mortality: the time of season when a particular heat-wave started and a warning variable indicating whether or not a heat-wave warning had been issued. An issue in this analysis is the small R^2 of 0.04 and the t of –1.43, which means that the probability of such a benefit by chance is about 8%, which is relatively high. However, the numbers were very small, so achieving statistical significance was not likely. The low R^2 implies that most of the variation in excess mortality is attributed to variables not included in the model, as would be expected.

Between 1995 and 1998, warnings were issued on 21 days, and the 24 days following a warning were included in the regression model. Philadelphia's system was therefore assumed to have saved the lives of 117 people. Assuming a value of US$ 4 million per life saved, the gross benefits of the Philadelphia heat health warning system were in the order of US$ 468 million, or US$ 117 million per year. As a reduction in morbidity was not included in the model, the heat health warning system had an additional benefit.

Part of the monetary costs of the system are indirect costs. These indirect costs arise from actions taken by city employees as a normal part of their jobs and actions taken by volunteers. These indirect costs have not been estimated.

The direct costs emerge from the Heatline and additional emergency medical service and are estimated to be about US$ 300 000 for the whole period of 1995–1998, or US$ 75 000 per year. Compared with the US$ 468 million dollars in benefits, these costs are very low. Nevertheless, estimating the indirect costs would be important in order to get a realistic estimate.

In 2002 the costs of single intervention measures were estimated again (Table 12) (Kalkstein, 2002). The total costs per year amount to about US$ 115 000. In addition to the annual costs, the costs of developing the system are between US$ 50 000 and US$ 60 000.

TABLE 12. COSTS OF SINGLE INTERVENTION MEASURES IN 2002 IN PHILADELPHIA

Intervention measure	**Cost per unit (US$)**	**Total summer 2002 (US$)**	**Remarks**
Heatline	2 950 (weekend) 1 220 (weekdays)	25 000	Salaries: US$ 19 000 Rest: meals, phone use, etc.
Issuance of fans	13 (per fan)	7 000	
Extended hours of senior centres		3 000	
Mobile teams	357–476 (weekend) 156 (weekday)	4 000	
Extended hours of the emergency medical services of the Fire Department	4 000	76 000	
Total per year		115 000	

Source: adapted from Kalkstein (2002).

4.6. Recommendations

4.6.1. Implementation of heat health warning systems

Based on the experience of existing heat health warning systems, several recommendations can be made for the implementation of such systems.

One of the key questions is where heat health warning systems should be set up. Although countries in southern Europe and the Balkans are more frequently subject to heat-waves, the populations of southern European countries have adapted to hot weather to some extent. However, countries in northern and central Europe might be less well adapted and may thus be vulnerable when an extreme event occurs. In addition, current evidence suggests that heat health warning systems could be set up in major cities but also should cover rural areas.

National meteorological services and health ministries should have joint responsibility for implementing heat health warning systems. This ensures rapid flow of information and combines the competencies of the meteorological and health staff involved in the warning system. Good coordination between the meteorological agency and health ministry is necessary. Heat health warning systems should speak with "one voice". At the country and local level, it might be further discussed which other institutions should be involved to ensure proper intervention planning.

In addition, a structure should be set up to ensure that all agencies involved have funding, with regular meetings between agencies to retain interest in the issue. The loss of funding for one of the involved agencies poses the danger of a loss of knowledge and interruption of the information flow if the agency has to leave the heat health warning system.

Because climate and culture differ within Europe, heat health warning systems should be developed to fit the local setting. One very important aspect is to adjust information flow and intervention measures to the local needs and the available infrastructure. However, having some standardization across systems to facilitate comparison and knowledge transfer would be beneficial. Regional coherence is required so that warnings are consistent from one town to the next.

4.6.2. Method of warning

Another key question is when to issue a warning. This question is related to the identification of a warning indicator related to the health impact of the thermal environment. There are many possibilities for such indicators, but few reflect the physiological relevance of the thermal environment. The warning indicator must be based on data that is easily available for the region of interest. Independent of the heat-wave indicator chosen, more than one level of warning is needed. A buffer zone should be placed around oppressive conditions, as a false-negative might influence severely the credibility of the system and be worse than a false-positive in some cases.

The thresholds of the warning indicator should allow for adaptation to be included combining a relative (local) and an absolute component. This ensures that, even under nonstationary climatic conditions (climate change and climate variability), thresholds and warning indicators will not have to be changed.

The thresholds should be based on a probability (risk) approach to avoid predicting the actual numbers of deaths.

4.6.3. Advice during heat events

Not only the heat health warning system as a whole but also the heat advice messages and the way they are delivered should be adapted to the social and behavioural context for the target population, especially with regard to northern, southern and eastern Europe. Different heat advice messages can be given to the different target groups. A message that is harmonized with the needs of the target group ensures that they understand the message and can implement the advice given. Even if using new ways to deliver messages is advisable, such as the Berlin subway messaging system, information paths should be used that are appropriate to the various target groups. For example, e-mail or SMS may not reach as many elderly people as desired.

As the advice given during a heat-wave should be contextual to place and include cultural considerations, more detailed advice will be needed for the populations in northern Europe that are not used to heat than in populations that are used to coping with heat.

The warnings should be targeted to the whole population, with special emphasis on the groups which are more vulnerable and on the institutions and organization responsible for their welfare:

- families with small children

- elderly people

- ill people

- tourists (in several languages)

- people who have to work outdoors.

In addition, the warnings should be sent to institutions, such as health service providers, organizers of sport events and care workers. Warnings should be communicated to electricity providers to avoid power failure.

During periods of severe heat, not only the heat itself affects human health but also ultraviolet radiation, ozone and other air pollutants that are directly or indirectly related to the weather conditions. To avoid many separate warnings and advice, the advice about heat should be linked to advice about protection against ultraviolet radiation and, if appropriate, air pollutants, such as ozone.

4.6.4. Education and training

Educational strategies are very important to raise the awareness of the hazard, so that the population is prepared when a heat-wave occurs. The following aspects should be considered for a long-term educational and health promotion strategy.

- At the community level, develop and distribute guidelines for each target group, such as schools, residential care homes, tourist resorts, clinics and hospitals.

- Provide information on such aspects as when fan use is appropriate, when to open windows and when to use window shades (see also section 5.5 on the indoor environment).

4.6.5. Emergency planning

Current evidence indicates that government services and health agencies are poorly prepared for severe heat-waves. Heat is not perceived as a problem at the government level. Since the measures required to mitigate heat effects are mostly simple, the government services sometimes underestimate the health risks. Heat-waves are often accompanied by power failures and failures in water supply. Severe heat-waves should therefore be included in emergency planning at the local and national level.

4.6.6. Recommendations on the evaluation of heat health warning systems

The review has shown that few evaluations of heat health warning systems have been undertaken. This information should be used for planning, implementing and ongoing evaluation. An evaluation should assess whether the system is serving a useful public health function and meeting the system objectives. First, the objectives of the system must be clearly described before the system is set up. Then the mechanisms for collecting the data needed for evaluating and monitoring the system also need to be established as the system is implemented.

The following steps should be taken to be able to evaluate a heat health warning system.

1. Describe the public health importance of "heat".

2. Describe the system to be evaluated:
    - objectives of the system
    - administrative structure of the system and agencies
    - scientific basis for the system
    - components and operation of the system
    - a flow chart of the system.

3. Public health usefulness of the system:
    - what actions are initiated in response to the warning(s) and who is responsible for these
    - if actions are not implemented, give the reason(s)
    - list other anticipated responses to be linked to the warning.

4. Describe the resources used to operate the system:
    - the costs of setting up the system (initial costs)
    - the annual cost of maintaining the system, including indirect costs
    - the estimated direct cost per warning or level of warning.

5. Evaluate the system for each of the following attributes:
    - transparency
    - integrity
    - acceptability
    - communication
    - effectiveness
    - sensitivity and specificity
    - timeliness
    - sufficiency of the system.

6. Evaluate the specific measures for each of the following attributes:
    - acceptability or credibility
    - timeliness
    - effectiveness.

4.7. Research gaps

Several research gaps were identified during the cCASHh Workshop on Vulnerability to Thermal Stresses.

- The role of minimum, maximum or daily mean thermal conditions for heat-related mortality and morbidity is still unclear and difficult to distinguish because the meteorological parameters are closely correlated.
- The effectiveness of heat health warning system and associated interventions to be evaluated.
- The responses of elderly people and other vulnerable groups to heat need to be better understood:
    - physiological effects
    - role of behaviour in responding to higher ambient temperatures
    - development of appropriate heat advice messages.
- The use of appropriate risk reduction measures, such as cooling facilities in hospitals, needs to be assessed for their effectiveness.

4.8. Current research into the development of heat health warning systems

Two research projects are currently developing appropriate methods for heat warnings. One is the Assessment and Prevention of Acute Health Effects of Weather Conditions in Europe project funded by the European Union and the other is the World Meteorological Organization (WMO) Expert Team on Operational Heat/Health Warnings.

4.8.1. Assessment and Prevention of Acute Health Effects of Weather Conditions in Europe

As the climate criteria for issuing warnings are often arbitrary and not based on the actual relationships between climate and human health, heat stress warning systems need to be developed for European cities that are based on sound principles and well-defined relationships between heat stress and mortality and morbidity. This is the aim of the Watch Warning System (WWS) work package of the European Union Fifth Framework Programme project entitled Assessment and Prevention of Acute Health Effects of Weather Conditions in Europe (PHEWE).

The overall aim of the WWS work package is to develop air mass–based heat stress watch warning systems for five European cities (London, Paris, Barcelona, Rome and Budapest) that can be applied to mitigate heat-related death and illness. The related objectives are:

- to develop a generic air mass classification system for the target cities and construct city-specific air masses based on statistical algorithms that will form the scientific basis of the WWS for the prediction of heat-related death and illness (the algorithms will describe the relationship between daily mortality (morbidity) and a range of standard and derived (rate of change and antecedent) daily meteorological and human energy balance-based heat stress index variables);
- to design a set of generic and city-specific mitigation measures for the reduction of heat stress–related mortality and morbidity as an integral part of a WWS for each city;
- to formulate protocols for implementing a WWS; and
- to install and undertake a ghost trial of the WWS for each target city and thus an evaluation of the potential effectiveness of the WWS and associated mitigation measures.

In achieving the final WWS, four linked stages of work will be undertaken.

1. *Statistical algorithm development.* Analyses leading to algorithm development will be based on stratified and unstratified daily mortality (morbidity) data. Stratification, according to population characteristics and air mass types, represents an innovative aspect of the method, as it is believed that vulnerability to heat stress–related death and illness depends on the interaction between population characteristics and offensive air mass types. To develop scientifically transparent and user-friendly prediction algorithms, relationships between air masses, weather and health will be modelled using standard linear regression, although the utility of more advanced techniques such as cluster analysis and regression tree analysis will be assessed. A range of forecasts, including binary, continuous, multicategory and probability forecasts, will be produced.

2. *Algorithm predictability*. Algorithm predictability and final model choice(s) will be established using a range of quantitative forecast skill scores and cross-validation.

3. *System operation protocols and mitigation measures.* Visits will be made to the five target cities: (a) to assess the candidature of potential WWS operators in the target cities, (b) to develop a set of generic and city-specific guidelines for WWS operation, (c) to identify WWS operator training needs,

(d) to design generic and city-specific intervention plans that can be operationalized for the mitigation of heat-related mortality and morbidity and (e) to develop WWS installation and testing guidelines. Workshop attendees are expected to be from stakeholder institutions such as health authorities and meteorological and emergency services in the target cities.

4. *System installation and testing.* WWS will be installed on a web site to facilitate a single summer (2004) ghost trial of the WWS. Health outcomes will be predicted and virtual warnings issued to the agency identified as responsible for implementing the WWS. The WWS stakeholder agencies will evaluate their ability to respond to the warning and to implement the intervention plans by self-assessing their degree of preparedness.

The cities developing the warning systems could use guidance on the evaluation of the system when developing them.

4.8.2. WMO Expert Team on Operational Heat/Health Warnings

A WMO Expert Team on Operational Heat/Health Warnings was established in 2001. The main tasks of the WMO Expert Team include the following.

1. Two more operational heat health warning systems will be developed for vulnerable cities that have good meteorological and mortality databases. At the moment, Casablanca and Delhi have been identified as suitable candidate cities.

2. Guidance material will be developed that will permit technology transfer to all potential locales with interest in heat health warning systems. This material will allow cities to independently develop their own watch and warning systems. It will include:

    - the data necessary to develop a system;
    - actual system development;
    - software installation;
    - operation and collaboration among local agencies that are significant stakeholders;
    - intervention plans that have proven successful in other areas; and
    - evaluation of the effectiveness of the system.

3. Systems may be expanded to include seasonal forecasts. The systems are designed for 48–60 hours of advance notice of a heat event. Many countries are now developing longer-range forecasts (3 to 6 months lead-time), but these are for seasonal weather, will still be experimental for years and cannot forecast individual weather systems.

The WMO Expert Team will provide general guidance for any city in developing a heat health warning system. The guidance will address the epidemiological analysis of meteorological and health data, the implementation of a forecast procedure and a range of interventions. The guidelines are scheduled to be available in 2004.

4.8.3. WMO Expert Team on Health-related Climate Indices and their Use in Early Warning Systems

Parallel to the WMO Expert Team on Operational Heat/Health Warnings, the WMO Expert Team on Health-related Climate Indices and their Use in Early Warning Systems was established. The terms of reference of this Expert Team include:

- to critically review and make recommendations on the efficacy and validity of universal thermal climate indices;

- to review and make arrangements for the continued quantification of the relationship between health stressors such as ozone, other environmental pollutants, vector- and waterborne diseases, adverse radiative impact, heat and cold stress on the one hand, and meteorological factors including climate indices;

- to identify or develop custom-built climate indices for vulnerability assessments, preparedness planning and alerts on particular health outcomes of climate variations; and

- to identify requirements for and make recommendations on the coordination of further research in the area of climate and human health.

In addition, a universal thermal climate index is being developed and will be compared with existing procedures and tested and validated for operational use (Jendritzky et al., 2002). It will then be presented to WMO and WHO with recommendations and guidelines for implementation.

5. URBAN BIOCLIMATOLOGY

5.1. Introduction

5.2. Urban climates and urban heat islands

5.3. Urban bioclimates

5.4. Urban planning, design and architecture

5.5. Indoor environment

5.6. Potential impact of climate change on urban climate

5.7. Discussion and recommendations

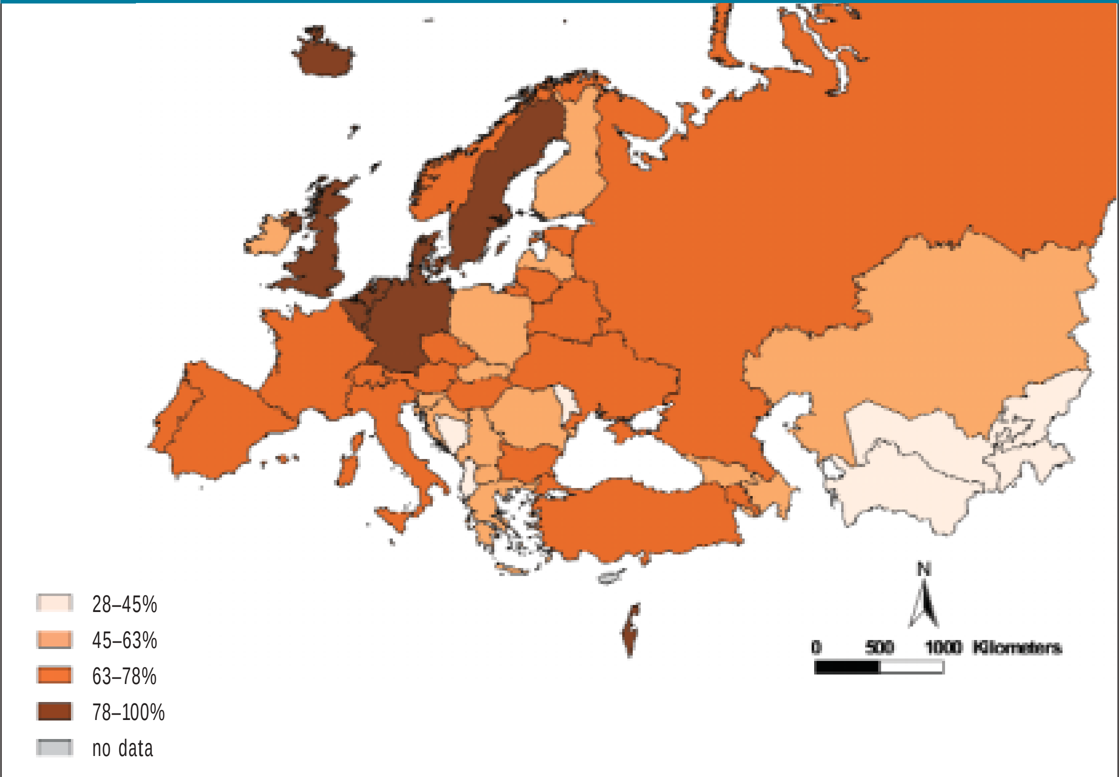
5.1. Introduction

Only 0.2% of the earth's surface is covered with urban areas (Matzarakis, 2001), but 47% of the world population and 73% of the population of Europe live in urban areas (Deutsche Stiftung Weltbevölkerung, 2002). The number of people living in urban areas is rapidly growing in developing countries. By 2007, half the world population is projected to live in urban areas. If trends continue (Arnfield, 2003), by 2025, the population living in cities will increase to 60% (Bitan, 2003). However, in western Europe and North America. there is a move out of the large cities into suburbs and smaller urban centres. Nevertheless, the urban population in Europe grew by about 0.4% between 1990 and 1995 (Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung, 2000).

This trend leads to the expansion of cities and creates a conflict between urban areas and the open spaces within and around them (Fig. 19) (Bitan, 2003).

Temperatures are higher in urban areas. This is caused by many factors, including less radiant heat loss in the urban canopy layer, lower wind velocities and increased exposure to radiation (Jendritzky & Grätz, 1999). Local and regional climates are modified significantly by urbanization and other land-use changes. Urban climates are modified by changes in the water balance, the radiation and energy budget and changes in the wind-field (Gross, 1996). Global climate change will interact with other important factors (urban planning and construction of the built environment) to affect urban bioclimates in the future (Wagner, 1994).

Fig. 19. Percentage of the population living in urban areas in countries in the WHO European Region, latest available data for each country



Source: Health for All Database of the WHO Regional Office for Europe

5.2. Urban climates and urban heat islands

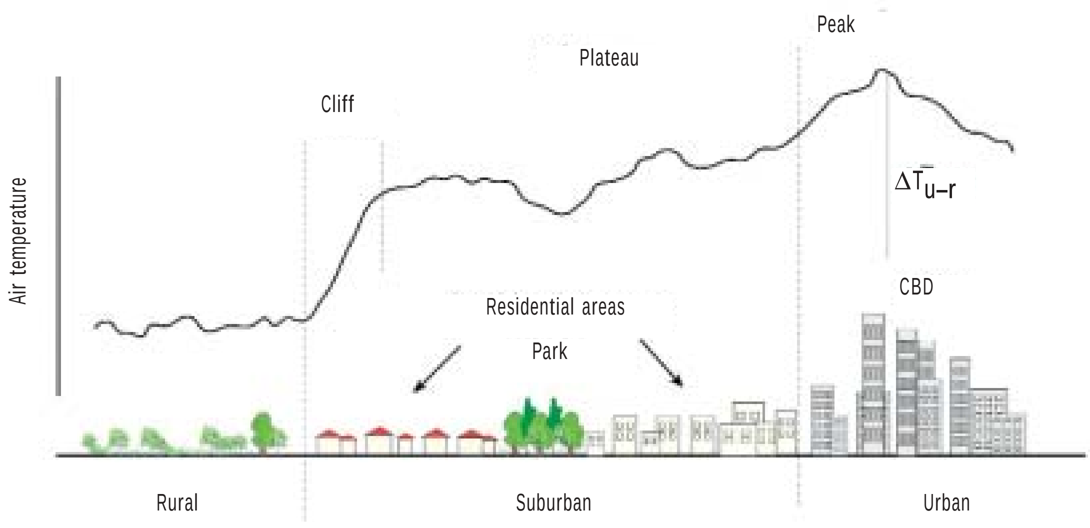
WMO (1983) defines urban climate as local climate that is modified by interactions between the built-up area (including waste heat and the emission of air pollutants) and regional climate. The climate of a city is a local mesoclimate (spatial extension about 250 km). The city affects both physical and chemical processes in the atmospheric boundary layer (the lowest 1000 m of the atmosphere) (Mayer, 1992; Fezer, 1995), including:

- flow obstacles;
- the area of an irregular elevated aerodynamic surface roughness;
- heat islands; and
- sources of emissions, such as sulfate aerosols that affect cloud formation and albedo.

Table 13 shows the modification of meteorological parameters in urban areas. One of the best known phenomena of the urban climate is the urban heat island. The term urban heat island denotes the increased temperature of a city compared with the temperature of the surrounding rural area. The temperature difference increases with an increase in the number of inhabitants and the building density. Fig. 20 shows a theoretical urban temperature cross-section. In the city itself, certain areas can be

Fig. 20. Theoretical urban temperature cross-section

CBD (central business district) ΔT_{u-r} (temperature difference between urban centre and rural area)



Source: Bitan (2003).

TABLE 13. COMPARISON OF CLIMATE VARIABLES BETWEEN URBAN AND RURAL AREAS

Meteorological parameter		Compared with rural areas
Radiation	solar radiation	less
	ultraviolet radiation (winter)	less
	ultraviolet radiation (summer)	less
	sunshine duration	less
Air temperature	annual mean	higher
	radiation days	higher
	minimum temperature	higher
	maximum temperature	higher
Humidity	relative	less
	absolute	no change
Fog		less
Cloudiness		more
Precipitation	annual mean	more
	snow	less
Wind	mean wind-speed	less
	calms	more
	gusts[4]	more
Contaminants	particles	more
	gases	more

identified that are warmer than other parts. Conversely, green spaces within the city cause urban cold islands, which are cooler than the rest of the city.

Many kinds of urban heat islands can be identified depending on what kind of temperature is examined.

The various urban heat islands display different characteristics and are controlled by different assemblages of energy exchange processes. For example, urban heat islands in the air temperature at different heights can be found. Another kind of urban heat island can be distinguished based on the temperatures of urban surfaces. Although surface temperatures show some similar spatial and temporal patterns to those for air temperatures, this correspondence is not exact (Arnfield, 2003). Depending on settlement structures, not only one urban heat island develops but an urban heat archipelago.

Because of different surfaces and building structures, there are different microclimates (such as street canyons, courtyards and parks) within the urban climate. The factors that differentiate urban climates from the surrounding rural area are anthropogenic heat production, airflow and built form (Yannas, 2001).

[4] *A gust is defined by the fact that wind velocity during the gust is more than 5.1 m/s higher than the mean wind velocity. The minimum duration of a gust is 3 seconds.*

Buildings are permanent heating appliances discharging heat all year round from space heating and cooling, artificial lighting and the use of domestic and office appliances. In northern Europe during winter, the amount of heat dissipated within the urban canopy layer by buildings and motorized transport can exceed that contributed from solar radiation. However, *anthropogenic heat release* depends on the role of building insulation (Arnfield, 2003).

The wind velocity in cities is generally lower than that in the open country.This results in a reduced rate of heat dissipation by convective cooling. Nevertheless, tall buildings and the channelling effect of urban canyons lead to complex *airflow* patterns and produce turbulence.

Built density and *built form* are composite variables combining parameters such as the area of exposed external surfaces, the thermal capacity and surface reflectance of built elements and the view of sun and sky by surfaces. A cubical form can collect more than three times the annual amount of radiation that would have fallen on unbuilt ground.

Under "ideal" (calm and cloudless) conditions at night, the effects of street canyon geometry on radiation and of thermal properties on heat storage release are the two main causes of the urban heat island. In very cold conditions, space heating of buildings can become a dominant cause depending on wall insulation (Ichinose et al., 1999).

5.2.1. Urban climates and air quality

Many cities have high levels of outdoor air pollution, especially carbon monoxide, nitrogen oxides, volatile organic compounds and particulate matter.The formation of photochemical smog may prevent solar radiation from reaching the ground and reduce the heat loss from long-wave radiation. Ground-level ultraviolet radiation is therefore often reduced during severe pollution episodes.

Air temperature, cloud cover and precipitation are higher in cities than in the surrounding areas. The mean wind speed is lower but gusts are more frequent. Insufficient air exchange in street canyons because of low wind speeds can decrease ground-level air quality.

5.2.2. Intensity

The urban heat island is relatively easy to measure, and several studies have identified factors that are associated with the magnitude of the effect.

5.2.2.1. The size of the town

The larger the urban area and the more people living in the city, the more pronounced is the urban heat island (Oke, 1973; Moreno-Garcia, 1994; Goldreich, 1995; Nichol, 1996; Yamashita, 1996; Chambers & Bazel, 2000 cited in Matzarakis, 2001).

In North America, the magnitude of the urban heat island is related to population size. Under ideal conditions, the maximum urban-rural difference of 2.5 °C for towns of 1000 inhabitants increases to 12 °C for cities of 1 million (Oke, 1973). European cities have lower per capita energy use and hence anthropogenic heat production than cities in North America and therefore smaller rural-urban differences. Other reasons for the smaller European heat islands may be the lower heat capacity of the urban environment and more evapotranspiration than in North American cities. However, this analysis did not include information about the relationship in cities in southern Europe.

The regression equations in Table 14 describe the log-linear relationship between the urban heat island (ΔT_{u-r}) and population size (P) for North America and Europe (Oke, 1973).

TABLE 14. RELATIONSHIPS BETWEEN THE URBAN HEAT ISLAND (ΔT_{u-r}) AND POPULATION SIZE (P)

Region	**Association**		**Cities in study**
North America	$\Delta T_{u-r} = 2.96 \log P - 6.41$	$r^2=0.96$ $s\ \Delta T^2 = \pm 0.7$ °C	Montreal, Vancouver, San Francisco, Winnipeg, Edmonton, Hamilton, San Jose, Palo Alto and Corvallis
Europe	$\Delta T_{u-r} = 2.01 \log P - 4.06$	$r^2 = 0.74$ $s\ \Delta T^2 = \pm 0.9$ °C	London, Berlin, Vienna, Munich, Sheffield, Utrecht, Malmö, Karlsruhe, Reading, Uppsala and Lund

Source: Oke (1973).

5.2.2.2. Topographic and climatic position of the city

Depending on the structure and direction of open rural areas near the city, nocturnal cold air penetration may be induced. This reduces the heat island intensity during the night. The urban heat island may also be reduced by regional wind systems such as sea breezes or wind systems in mountain valleys (Clarke, 1969; Böhm & Gabl, 1978; Bernhofer, 1984; Goldreich, 1984; Nasrallah et al., 1990; Adebayo, 1991; Jauregui et al., 1992; Kuttler et al., 1996; Tso, 1996; Baumbach & Vogt, 1999; Padmanabhamurty, 1999; Ali, 2000; Asaeda et al., 2000; Jonsson, 2000; King'uyu, 2000; Okpara, 2000; Saaroni et al., 2000 cited in Matzarakis, 2001).

Wienert (2001) analysed the maximum urban heat island of 150 cities all over the world (46 European cities, Table 15). He found that the urban heat island depends on geographical latitude because of anthropogenic heat production, the radiation balance and its annual variability vary according to latitude. The maximum differences between urban and rural environments in the lower latitudes are smaller than in the higher latitudes. For example, the maximum urban-rural differences are 8.7 °C in Amsterdam and 3 °C in Parma. Wienert's findings indicate that the relationships found by Oke (1973) are only valid in regions with more or less the same geographical latitude. Basically a fair variance must be considered and different authors have found different maximum heat islands. One study estimates the maximum urban heat island of Gothenburg to be 8.5 °C, nearly twice the estimate of Wienert. Another study (Santamouris, 1998 cited by Matzarakis, 2001) determined the maximum urban heat island for Athens during daytime in summer to be 18 °C. Wienert found only 7.5 °C.

5.2.2.3. Distribution of the urban structures

The hottest zones in the city are those with the tallest buildings and the highest density of buildings, without green spaces and with intense generation of anthropogenic heat (Eriksen, 1976; Roth et al., 1989; Asaeda et al., 1996; Eliasson, 1996; Upmanis et al., 1998; Goh & Chang, 1999; Santamouris et al., 1999; Unger, 1999; Eliasson & Upmanis, 2000; Pinho & Manso Orgaz, 2000 cited in Matzarakis, 2001).

5.2.3. Trends over time

Several studies have investigated changes in the urban heat island over time (Böhm, 1979, 1998; Cayan & Douglas 1984; Katsoulis & Theoharatos, 1985; Feng & Petzold, 1988; Karl et al., 1988; Kozuchowski et al., 1994; Karaca et al., 1995; Hughes & Balling, 1996; Nakamura, 1998; Magee et al., 1999; Philandras et al., 1999; Green et al., 2000 cited in Matzarakis, 2001).

TABLE 15. EUROPEAN CITIES AND MAXIMUM URBAN HEAT ISLANDS

City	Maximum urban heat island (°C)
Lund (Sweden)	2
Parma (Italy)	3
Reykjavík (Iceland)	3
Lünen (Germany)	3.5
Osnabrück (Germany)	3.5
Valencia (Spain)	3.6
Biel (Switzerland)	4
Reading (United Kingdom)	4.4
Lisbon (Portugal)	4.5
Annecy (France)	5
Fribourg (Switzerland)	5
Gothenburg (Sweden)	5
Giessen (Germany)	5.5
Cologne (Germany)	5.7
Freiburg (Germany)	6
Graz (Austria)	6
Rome (Italy)	6
Stockholm (Sweden)	6
Stolberg (Germany)	6
Szeged (Hungary)	6
Vienna (Austria)	6
Bochum (Germany)	6.6
Malmö (Sweden)	7
Munich (Germany)	7
Sheffield (United Kingdom)	7
Uppsala (Sweden)	7
Zagreb (Croatia)	7
Athens (Greece)	7.5
Aveiro (Portugal)	7.5
Essen (Germany)	7.5
Karlsruhe (Germany)	7.5
Moscow (Russian Federation)	7.8
Barcelona (Spain)	8
Bucharest (Romania)	8
Helsinki (Finland)	8
Lódz (Poland)	8
Sverdlovsk (Russian Federation)	8
Utrecht (Netherlands)	8
Amsterdam (Netherlands)	8.7
Irkutsk (Russian Federation)	9
Berlin (Germany)	10
Birmingham (United Kingdom)	10
Cita (Russian Federation)	10
Dortmund (Germany)	10
London (United Kingdom)	10
Lipeck (Russian Federation)	12

Source: adapted from Wienert (2001).

A study of urbanization in Athens found that a rapid increase in population and in the number of motor vehicles with a decreasing trend in precipitation caused the maximum temperatures to increase from the 1940s until 1990 (Philandras et al., 1999). Bràzdil & Budiková (1999) analysed the development of the Prague urban heat island from 1922 onwards. They found an increase in the heat island of 0.06 °C per year in winter and spring and of 0.01 °C per year in summer until 1960. Since 1960, the trend in the urban heat island has stagnated.

Wilby (2003) attributes the more rapid nocturnal warming in spring, summer and autumn in central London compared with a rural site between 1961 and 1990 to the presence of polluted air in the urban atmosphere, which absorbs and then re-emits outgoing terrestrial radiation at night, and to anthropogenic heat production in the form of increased air-conditioning in recent decades.

The magnitude of the urban heat island is limited (Oke, 1973) because constructing new city structures requires demolishing old city structures once a given level of urban development has been reached, so that concrete replaces concrete. In addition, a large urban-rural temperature gradient induces a convergent thermal breeze circulation.

5.2.4. Variability

The processes and phenomenon of urban climate depend on weather conditions, the time of day, the time of year and the location of the city (the meso- and macroclimate of the city). The urban heat island is most pronounced during calm, clear nights in winter.

5.2.4.1. Weather

The intensity of the urban heat island peaks under autochthonal (anticyclonic) weather conditions (Oke, 1976, 1998; Nkemdirim, 1980; Balling & Cerveny, 1987; Kidder & Essenwanger, 1995; Unger, 1996; Figuerola & Mazzeo, 1998; Pinho & Manso Orgaz, 2000 cited in Matzarakis 2001).

5.2.4.2. Annual variability

The urban heat island in cities at middle latitudes is more pronounced in summer than in winter. Wilby (2003) found that the nocturnal urban heat island in London is on average strongest in August (+2.2 °C) and weakest in January (+1.1 °C). Arnfield (2003) reviewed the literature on the intensity of the urban heat island and concluded that it is most pronounced during the summer or the warm half of the year. However, studies (Montávez et al., 2000) show that the urban heat island in lower geographical latitudes (such as southern Europe) is more pronounced in winter than in summer.

5.2.4.3. Diurnal variability

Because of nocturnal radiative cooling in rural areas, the urban heat island is more pronounced at night than during the day (Oke & Maxwell, 1975; Helbig, 1987; Johnson et al., 1991; Oke et al., 1992; Jauregui, 1993; Runnals & Oke, 1998; Klysik & Fortuniak, 1999; Bai & Kubo, 2000; Barton & Oke, 2000; Boo & Oh, 2000; Gallo & Owen, 2000; Montávez et al., 2000 cited in Matzarakis, 2001; Kim & Baik, 2002; Livada et al., 2002).

The negative impact of the urban heat island appears mainly in the summer because the heat island increases exposure to high summer temperatures. Further, the urban heat island maintains higher temperatures at night. This is thought to increase the impact on health of continuous hot days, as little relief is experienced at night (see also section 5.5).

5.3. Urban bioclimates

Traditional studies of heat islands usually do not include bioclimatic aspects and are therefore of limited use to urban planners. What is needed is an evaluation of the effects of anthropogenic changes in the thermal environment related to human health and wellbeing (Jendritzky & Nübler, 1981).

Temperature, humidity, air movement and radiant energy exchange are important for maintaining the heat balance of the human body (Clarke, 1972; Jendritzky, 1983). Urban structures modify all these climate elements.

During daytime in summer, higher air temperature, lower wind intensity and spatially varying radiation conditions can lead to heat stress. Behavioural adaptation is necessary during heat stress situations: wearing appropriate clothing and avoiding direct solar radiation. The degree of heat load is mainly determined by solar radiation. The heat load is very high in direct sunlight (Jendritzky & Sievers, 1989). People with poor circulation should avoid open-air activities during the hottest time of the day.

Heat-waves present special problems in urban areas because buildings retain heat if ventilation for cooling at night is inadequate. During heat-waves, inhabitants of urban areas may experience sustained thermal stress both day and night, whereas inhabitants of rural environments often obtain some relief from thermal stress at night (Clarke, 1972; Jendritzky, 2000).

Green spaces, especially those with broad-leafed trees, have an important effect on the bioclimate of an urban area by providing shade. Sun and shade lead to extreme differences in the thermal conditions in a very small space. These differences emphasize the great importance of a microscale view of the bioclimate in an urban area (Jendritzky & Sievers, 1989; Matzarakis, 2001).

The following are two case studies on bioclimates in European cities: Szeged, Hungary and Berlin, Germany.

5.3.1. Szeged

Unger (1999) examined the influence of a medium-sized city (Szeged, Hungary) on the bioclimate conditions of humans. He used the following indices to assess the difference between urban and rural bioclimates:

- thermo-hygrometric index (THI (°C)): air temperature, relative humidity (comfortable = 15.0–19.9 °C);

- relative strain index (RSI): air temperature and vapour pressure (comfortable > 0.2); and

- the number of "beer garden days": air temperature exceeding 20 °C at 21.00.

Unger concluded that modifications of the main climatic elements in Szeged are mostly favourable for thermal comfort. In the urban environment, 30% of the days were in the comfort range, whereas in the rural environment only 20% of the days can be classified as comfortable. In contrast, in the city 6% of the days were classified as hot versus 1% in the surroundings. "Beer garden days" did not occur in rural environments.

5.3.2. Berlin

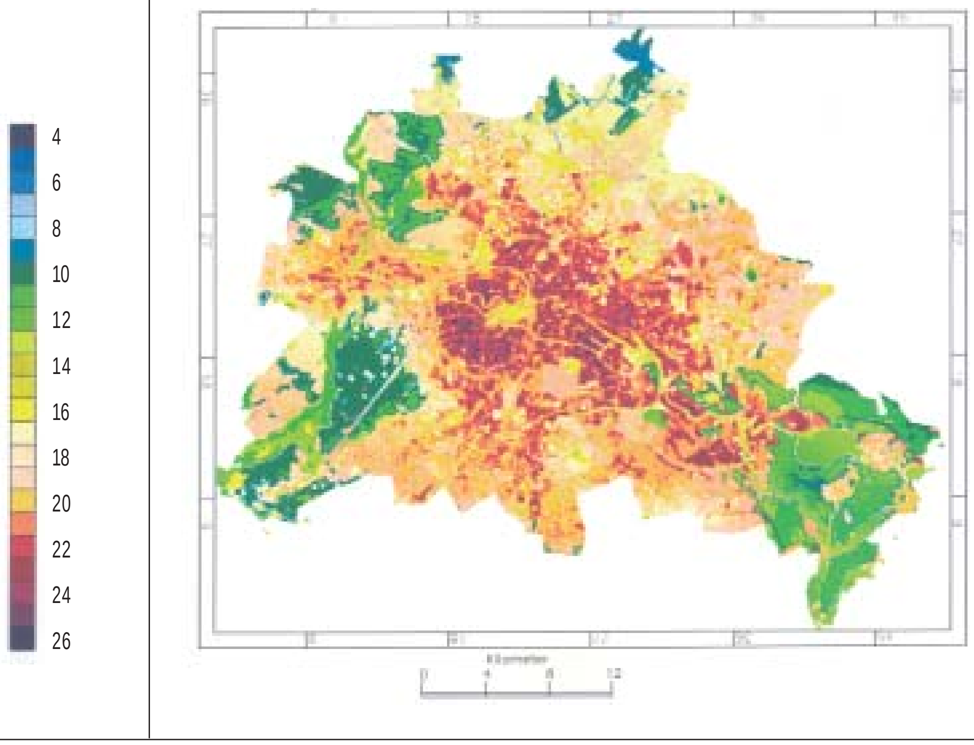
Measuring meteorological fields in the urban canopy layer is very expensive. In addition, the meteorological components of a city cannot be measured in the detail required for bioclimatological assessment. The modelling of these fields should therefore be emphasized. This approach also enables the impact of different planning options on the urban bioclimate to be assessed. Modelling seems to be the appropriate method of generating the relevant data for urban planning purposes with the aim of creating and safeguarding healthy conditions.

To meet the needs of urban planners, the Deutscher Wetterdienst developed the urban bioclimate model UBIKLIM as an expert system that utilizes available knowledge in urban climate science in an objective procedure for practical applications. Using geographical information system techniques, UBIKLIM simulates the thermal environment in the urban boundary layer that depends on the kind of land use: the given or planned settlement structure (these are the planning variables to be transformed into boundary layer parameters). Interactions between neighbouring structures, the topography (local scale) and the meso- and macroclimate are taken into account (Jendritzky, 1988; Jendritzky & Grätz, 2003). As input data, UBIKLIM requires a digital height model with 10 metres of resolution and appropriate information on land use. Dividing the urban area into a limited number of districts is sufficient, each characterized by its own land-use type. The main types are water, forest, parks, meadows, paved and unpaved open spaces and built-up areas. To differentiate the varying urban structure, the built-up area is divided up further considering the degree of pavement area, building density, building height and degree of green coverage. The result is a widespread and detailed bioclimate map on the horizontal heat load distribution with 10 metres of resolution that provides the necessary information for urban planners, health professionals and other decision-makers (Jendritzky & Grätz, 2003).

UBIKLIM was used to assess the thermal situation of Berlin in 1996 (Piehl & Grätz, 1996). UBIKLIM enables the urban climate to be assessed and thus facilitates the consideration of urban climate issues in planning and decision-making (Jendritzky et al., 1994). The thermal component of the bioclimate is evaluated by determining the physiologically relevant meteorological quantities from land use and the urban canopy layer and by analysing these quantities for a single cloudless summer day with the Klima Michel model. The result is a bioclimatic map (Fig. 21) that enables a relative evaluation and comparison of the bioclimate of different urban areas (Grätz & Jendritzky, 1998).

The bioclimate of a city depends on both regional factors (topographic situation and latitude) and local factors (urban structures). To assess the thermal situation, a mesoscale statistical bioclimatic model determines the regional part and UBIKLIM determines the local part. In contrast to UBIKLIM, which is calculated for one single day, the background situation was determined for a 30-year period (1951–1980). Based on these models, the annual number of days with heat stress can be determined.

Fig. 21. Annual number of days with heat stress in Berlin



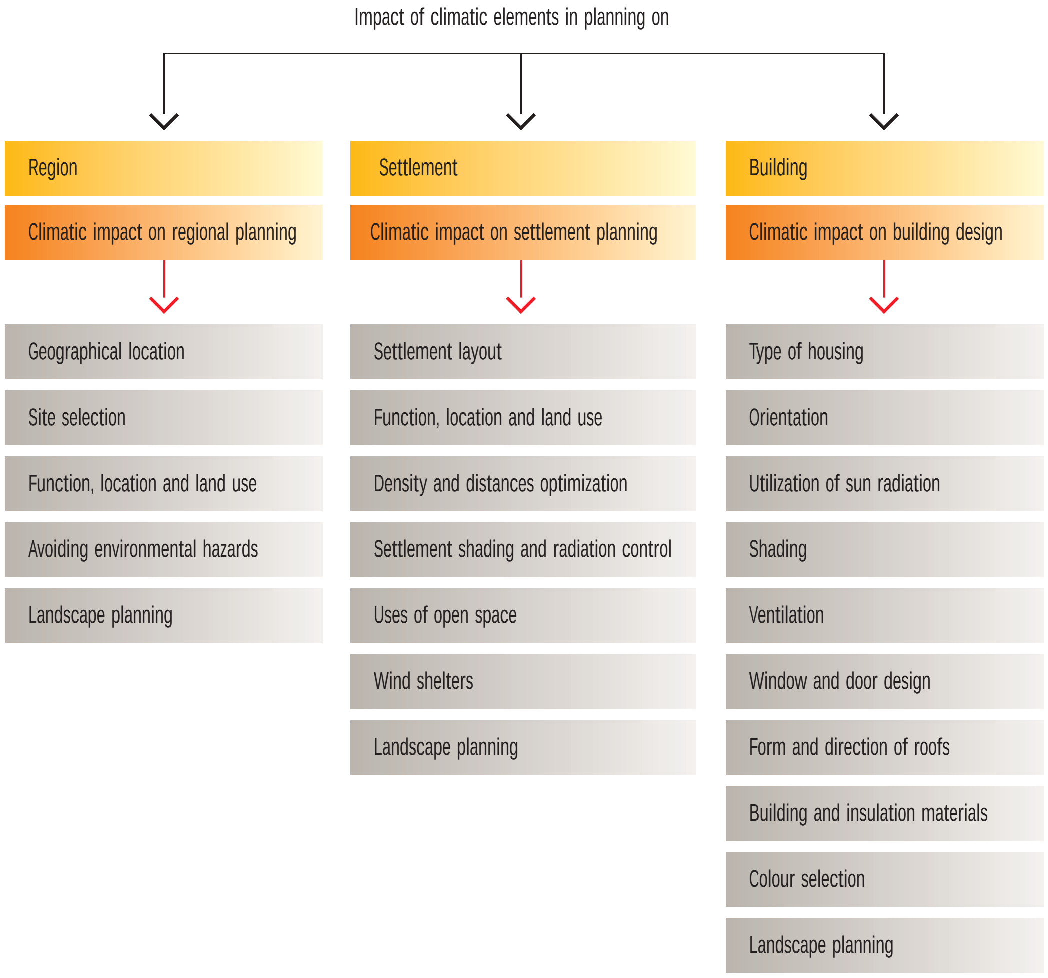
Source: Grätz & Jendritzky (1998).

5.4. Urban planning, design and architecture

Appropriate urban planning and building design provide measures to reduce heat stress for individuals living in cities and can reduce the urban heat island. The heat load becomes more extreme if the human body is directly irradiated by solar radiation, and planning measures that provide shade for pedestrians (trees, arcades and narrow streets) can therefore reduce heat load (Jendritzky, 1988). Appropriate architecture can prevent buildings from warming up and thereby ensure a comfortable indoor environments without the use of artificial air-conditioning. Architecture considers individual buildings, whereas urban design deals with planning the structure of settlements.

To maximize thermal comfort in urban areas, climatic aspects should be considered in all scales, from the design of the individual building to regional planning. Fig. 22 summarizes the impact of climatic elements on regional settlement planning (urban design) and building design.

Fig. 22. Impact of climatic elements on regional and settlement planning and building design



Source: Bitan (1988).

5.4.1. Urban design

Whereas research into indoor comfort is well developed, the impact of the outdoor thermal environment in urban spaces has received less attention. Although the outdoor thermal environment may not be comfortable all the time, the surrounding human-made and natural features can potentially create a multitude of microclimates through pockets of sun and shade, with varying degrees of protection or exposure to wind (Forwood et al., 2000).

The following questions are of interest to urban planners in optimizing health, well-being and performance (Grätz et al., 1994; Jendritzky, 1995).

- Which urban settlement structures tend to be stressful to the bioclimate?
- How can development plans be optimized with respect to human health?
- Which arguments for development regulations can be derived?
- Which areas are appropriate for new developments?
- Where is action urgently needed?

5.4.1.2. Problems in implementing climatic aspects in urban design

Urban design has no dominant goal, and the designer must deal with all scales of decision-making from the regional scale to the individual building. Climate considerations often have little effect on urban planning. Although urban planners are interested in climatic aspects, the use of climate information has low priority. To facilitate the influence of climate into urban planning, Eliasson (2000) suggests incorporation of the following steps:

- improve awareness of urban climate;
- improve communication between planners; and
- develop tools and courses suitable for urban planners.

Planning guidelines should take into account the following climatic aspects (Verein Deutscher Ingenieure, 1998; Scherer et al., 1999).

- ventilation: maintain and improve ventilation paths, restore connection to ventilation paths and reduce the risks of hazards caused by wind;
- air quality: maintain transport of fresh air and reduce pollution in areas with sensitive populations; and
- thermal situation: reduce heat load and reduce the negative effects of frost or cold stress.

De la Croix (1991) describes a more detailed way for implementing measures that reduce the urban heat island:

- identifying a city’s current temperature trend;
- identifying a city’s motivating factors that fit that city’s circumstances (reduction of energy costs, air quality and social impact);
- developing an overall plan and strategy; and
- documenting the savings.

5.4.1.3. Elements of urban design affecting urban climate

The following elements of town design affect urban climate, comfort conditions and energy use (Givoni, 1986):

1. size and density of the built-up area:

    - the microclimate in the immediate vicinity of green spaces differs from that prevalent in unplanted areas;
    - vegetation has lower heat capacity and thermal conductivity than building materials;
    - solar radiation is absorbed so that the reflected radiation is very small (low albedo);
    - green spaces have higher evapotranspiration rates than unplanted areas;
    - plant leaves can filter dust out of the air;
    - green spaces reduce wind speed and its fluctuation near the ground. In hot, dry climates, reducing wind speed during daytime may be desirable, whereas thermal stress is better reduced in humid regions by natural ventilation and planting trees with high and broad canopies that provide shade without impeding ventilation near the ground level (Nieuwolt, 1986);

2. layout and width of streets, their orientation and relation to the prevailing winds;

3. patterns of subdivision and the shape, size and orientation of building lots;

4. the height, shape and relative location of buildings;

5. shading conditions along streets and parking areas; and

6. ensuring short distances for walking.

Cities can be planned to reverse the heat island phenomenon (Givoni, 1986). Increasing the albedo of a city (such as painting roofs white) may cause negative radiation balance so that long-wave heat loss will exceed the solar heat gain. Since city size and higher density render the urban area more independent of the regional climate, any such lowering of urban temperature would be more noticeable in larger and denser urban areas.

Several studies have analysed the impact of single urban structures on the thermal environment and on human comfort conditions (Table 16). These studies provide good evidence that reducing building density, planting trees and laying out green spaces reduces heat stress in urban environments.

5.4.1.4. Case study: Stuttgart (Germany)

In 1951, the Lord Mayor of Stuttgart ordered all municipal agencies whose actions can affect the city's climate to consult climatologists. Since 1976, Germany's Federal Building Code has stipulated that climate, air pollution and health must be important factors in urban planning. Stuttgart began to involve municipal climatologists in urban planning earlier than other cities. In 1938, the municipal council decided to employ a meteorologist to investigate the urban climate of Stuttgart and to develop collaboration with town planning. Since that time, urban climate has been a very important factor for town planning in Stuttgart.

The activities of the Department of Urban Climate are limited to the boundaries of Stuttgart, where about 590 000 people live. The main fields of study are urban climate, air pollution and noise. Getting

TABLE 16. STUDIES OF PLANNING OPTIONS AND THERMAL ENVIRONMENTS

City	Year	Results	Reference
Changes in land use			
Berlin	1994	Potsdammer Platz and Spreebogen: planned changes in building density will lead to an additional increase in air temperature by 1–2 °C and to a reduction of wind speed by 80%	Wagner (1994)
Effect of trees in street canyons			
Munich	1985	Comparison of street canyons (north–south) with and without trees Trees had little effect on air temperature at 1.10 m above ground level Trees greatly affected mean radiant temperature (maximum 28 °C) Trees reduced extreme heat stress (predicted mean vote 3.5) to moderate heat stress (predicted mean vote 1.5) The physiological equivalent temperature was reduced from 46 °C to 31 °C, reducing heat stress by 40% The mean radiant temperature is the meteorological parameter with the greatest effects on the predicted mean vote and physiological equivalent temperature	Mayer (1996)
Effect of green spaces			
Berlin	1985	Extremely wind-still days Green spaces of 30 ha: the air temperature fell in the immediate vicinity up to distances of 150 to 600 m In a green space of 212 ha, influence could be measured up to a distance of 900 m on its lee-side.	Kuttler (1988)
Bonn	1974	The influence of green spaces on temperature extends up to distances of 250 m around the green space	
Waldkirch (Germany)	1994	Planning options simulated using the urban bioclimate model UBIKLIM Heat stress reduction (predicted mean vote) resulting from lower building density (36% instead of 50%) Additional reduction in heat stress by planting trees	Grätz et al. (1994)
Effect of water bodies			
Tel Aviv (Israel)	2000	Impact of a small lake on heat stress (within 40 m at the downwind side) (Discomfort index = 0.5 * (dry bulb temperature + wet bulb temperature) Compared with the upwind side, the downwind side of the pond had: • lower air temperature; • higher relative humidity; • lower heat stress index: the discomfort index declined at midday by 0.8–1.6; and • no significant change in water vapour pressure.	Saaroni & Ziv (2003)
Effect of courtyards			
Berlin	July 1999	Bioclimatic situation in the centres of three courtyards in Berlin on a hot summer day during daytime	Mertens (1999)

Courtyard area (m^2)	Predicted mean vote fast walking	Predicted mean vote sitting
12 600	0.0–2.8	–3 to 2.8
4 370	0.2–2.0	–3 to 1.2
180	0.2–0.9	–3 to –1.7

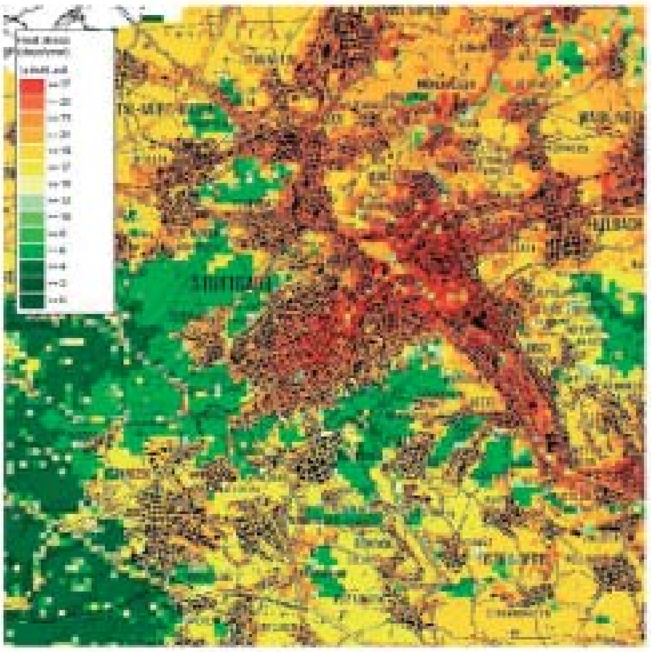
detailed values for both air pollution conditions in Stuttgart and meteorological parameters has been increasingly necessary. This requires buying expensive instruments, including an automated station for air quality control and a mobile measuring station. The demand for detailed data led to infrared pictures being taken by remote sensing in 1988 wich show the contrast between the countryside and the city. Although these pictures only show the surface temperature, the measurements were very helpful in preparing the new development plan of Stuttgart.

The baseline investigation for the climate atlas in 1992 involved remote sensing by aeroplane (infrared heat), meteorological measurements, a digital orographic model and maps of the air-emmission structure. The results of the investigation were thermal maps of the ground, maps of air temperature, air humidity, wind velocity and thermal comfort, a climatic analysis map and a map with hints for planning.

The number of days with heat stress, based on Klima Michel simulations, averages 27 days per year in the city versus only 6 days in the forest areas around the city (Fig. 23). The Department of Climatology tries to make all the results of its investigations available to the public. They therefore publish their own series of communications and CD-ROMs. Since 1976, Germany's Federal Development Law has stipulated that climate, air pollution and health be important factors in urban planning.

Stuttgart's practices can very well serve as a model for other cities in Germany and elsewhere. This kind of awareness of climatic factors is the exception rather than the rule.

Fig. 23. Number of days with heat stress in Stuttgart / year



Source: Baumüller (2003).

5.4.2. Cost and benefits of planning options

Planting trees and increasing green spaces is one method of reducing heat stress within a city. The costs of tree-planting projects include planting, pruning and watering the trees and removing dead trees. The benefits include shading, cooling by evapotranspiration, dust control, runoff control, consumption of carbon dioxide and water conservation. A study in Munich compared street canyons with and without trees (Mayer, 1996). Trees had little effect on air temperature at the level of human height but were effective in reducing heat stress by reducing radiant temperature.

An analysis in the United States of the potential of vegetation in reducing summer cooling loads in residential buildings in cities found that an additional 25% increase in urban tree coverage can save 40% of annual cooling energy in Sacramento, CA and 25% in Phoenix, AZ and Lake Charles, LA (Huang et al., 1987). The calculated savings were minimal in Los Angeles, which used little energy for cooling. The costs and benefits of urban trees in Tucson, Arizona, over 40 years of planting 50 000 trees were estimated at US$ 9.61 per tree versus total benefits of US$ 25.09 per tree (McPherson, 1991). An internal rate of return (which incorporates the time value of money in investment analysis) of 7.1% is projected for the entire tree planting project. A second project aimed to estimate the costs and benefits of planting trees for shading bus stops. Trees were compared with the construction of metal bus shelters. Again, the total costs for trees for a 40-year period were only half the costs for metal bus shelters.

A study by the United States Department of Energy (McCulloch, 1991 cited by Bitan, 2003) found that the costs of the heat island effect on a summer afternoon in Los Angeles are about US$ 150 000 per hour. If there are about 500–1000 hours of annual residential cooling in the Los Angeles area, then the annual costs of the urban heat island effect increase to about US$ 100 million for cooling. The excess power demand in the Los Angeles area was calculated to be about 300 MW per °F. This means that the 5 °F temperature increase caused by the urban heat island in Los Angeles increases the power demand by about 1.5 GW.

The impact of measures to reduce the magnitude of the urban heat island on ground-level ozone concentration were estimated in cities in the northeastern United States (Hudischewskyj et al., 2001) as part of the Heat Island Reduction Initiative of the United States Environmental Protection Agency. The effects of two measures (increasing the albedo and the vegetation cover) were analysed using the meteorological and photochemical modelling tool Systems Applications International Mesoscale Model. The Model was run for the heat episode period of 9–15 July 1995. The maximum decrease of the urban heat island was calculated for four simulations: full implementation of the measures, only increasing the

TABLE 17. MAXIMUM DECREASE (°C) OF THE URBAN HEAT ISLAND FOR 14–15 JULY 1995 COMPARED WITH THE BASE CASE

Measures implemented	14 July 1995	15 July 1995
Albedo + vegetation 100%	1.2 °C	0.9 °C
Only albedo	1.1 °C	0.6 °C
Only vegetation	0.4 °C	0.2 °C
Albedo + vegetation 50%	0.7 °C	0.4 °C

Source: Hudischewskyj et al. (2001).

albedo, only increasing the vegetation cover and partial implementation (50%) of both measures (Table 17). Increasing only the albedo of a city is nearly as effective as implementing both measures. However, increasing the vegetation cover has more influence on radiant temperature than on air temperature. The mean radiant temperature is the meteorological parameter with the greatest effect on the sensation of thermal stress in humans (Jendritzky, 1988; Mayer, 1996).

Good building design can provide effective measures to reduce the heat stress of individuals living in cities. A report on adaptation in the United Kingdom (Environmental Resources Management, 2000) concluded that many planning processes and systems had the capacity for integrating climate change considerations but required more robust and reliable information on the potential impact of climate change and better understanding of the importance of adaptation by stakeholders.

In Athens, Santamouris et al. (2001) showed that the urban heat island may double the cooling load and triple the peak electricity load for cooling purposes of urban low-energy buildings: those with many energy conservation features to decrease heating and cooling needs. During the winter, the urban heat island reduced the heating load of centrally located low-energy buildings by up to 30%. The authors do not provide information about the energy consumption of "normal" buildings.

Unfortunately, few studies aim to assess the costs and benefits of the different options for reducing the urban heat island and the heat load in buildings in Europe. In 2001 the BUGS (Benefits of Urban Green Space, http://www.ruhr-uni-bochum.de/bugs/index.html, accessed 29 October 2003) project started. This project, funded by the European Union, aims to develop an integrated method for assessing the benefits of urban green space.

5.5. Indoor environment

5.5.1. Introduction

One function of buildings is to provide shelter and protection from the elements and against outdoor climate. Providing safe, healthy environments and taking into account the prevailing climatic conditions are therefore important. Humans have considerable capacity to adapt to varied climates and environments. Physiological and behavioural differences between cultures have developed over many millennia as a consequence of exposure to vastly different climatic regimes. Most homes have an indoor temperature between 17 °C and 31 °C. Humans cannot live comfortably in temperatures outside this range. The tolerance range of an individual is usually less than this and tends to get narrower with age or infirmity.

In European countries, people spend the vast majority of their time indoors, at home and at work. The indoor environment has been investigated in relation to indices of thermal comfort. Perceptual scales have been developed to evaluate thermal comfort in an individual (such as the ASHRAE scale). In temperate climates, the optimum indoor temperature for health is between 18 °C and 24 °C (WHO Regional Office for Europe, 1987). Warmer climates have a higher limit of comfortable temperature, such as 28 °C in Greece and 25 °C in France. Most recommendations have focused on maintaining minimum indoor temperatures and reducing the impact of cold on health rather the potential impact of heat (WHO, 1990).

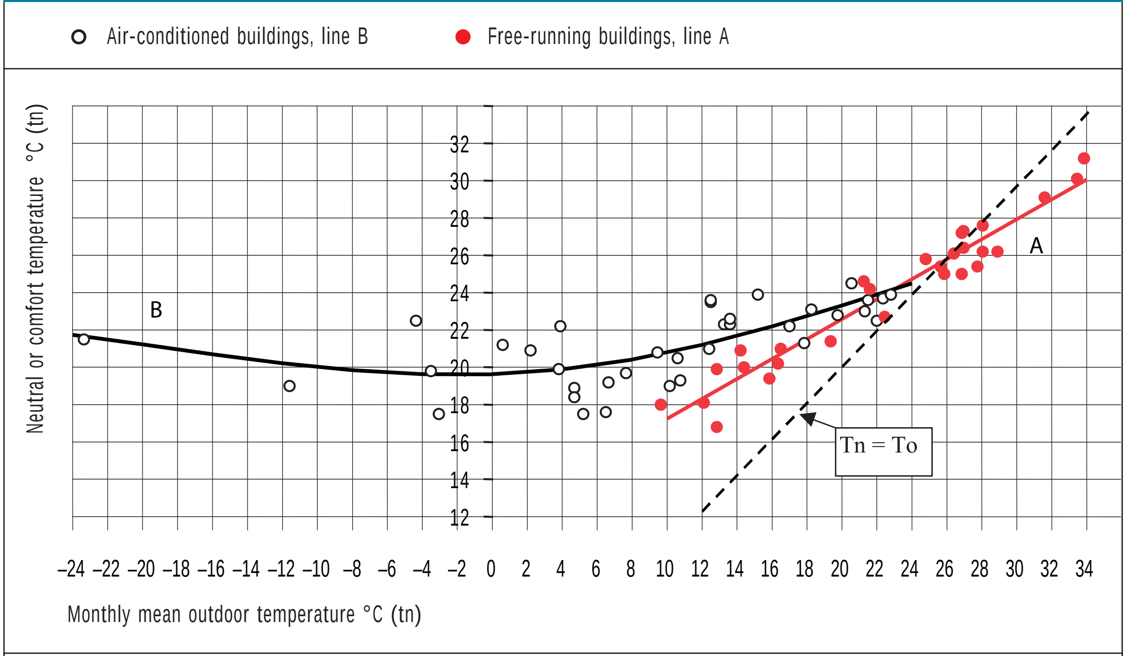
When conditions differ from comfort conditions, productivity and efficiency are likely to be adversely affected. Reduced mental concentration because of discomfort can lead to an increased risk of accidents. In addition, some people with existing health conditions such as heart problems, high or low blood pressure, respiratory conditions and kidney disease may be susceptible to adverse health effects from working in hot and/or humid conditions. Thermal comfort is determined by subjective judgement, and even in optimal conditions, some individuals may experience discomfort.

The indoor comfort temperature depends on the outdoor temperature (Fig. 24). The comfort thermopreferendum is not constant but depends on levels of acclimatization, habituation and expectation (psycho-physiological adaptation) (Humphreys, 1978; Auliciems 1981, 1983, 1992). A study in a variety of cities found a linear relationship between the comfort indoor temperature and the mean monthly outdoor air temperature, especially in buildings that were free-running or naturally ventilated (De Dear & Brager, 2001). This relationship was valid for an outdoor temperature range between 5 °C and 32 °C. The lower outdoor temperature was associated with an indoor comfort temperature of 19 °C and the upper with 32 °C. In buildings with air-conditioning, the indoor temperature is decoupled from the outdoor temperature and the relationship between outdoor temperature and indoor comfort temperature is much less strong.

Various studies show that many people wear the same clothing in different seasons, regardless of the climatic conditions prevailing outdoors in that location. An inherent assumption involved in this procedure is that the subjective reactions of people who stay indoors to temperature, air speed and other factors are independent of the conditions prevailing outdoors (Givoni et al., 2003). Others studies show, however, even in air-conditioned buildings, a negative relationship between clothing insulation and outdoor temperature.

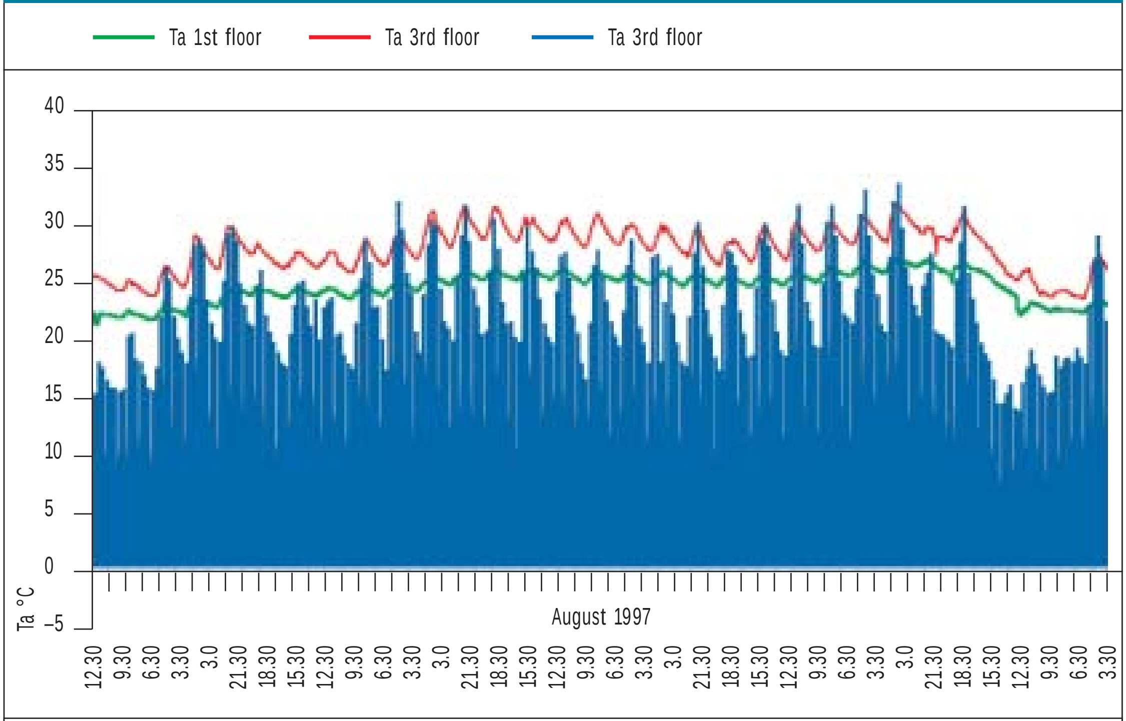
Indoor air temperature, air movement, humidity and the radiation temperature of indoor surfaces affect the indoor thermal comfort. Another factor affecting health indoors is indoor air quality, which is not discussed here. Bitan (1988) states that, in most cases, planning buildings according to climatological rules does not significantly increase the building costs, but it improves the quality of life and money is saved by using less conventional energy for air-conditioning and heating.

Fig. 24. Relationship between monthly mean outdoor temperature and comfort temperature



Source: Humphreys (1978).

Fig. 25. Indoor temperature on the first floor (Ta 1st floor) and third floor (Ta 3rd floor) of a building compared with the outdoor temperature (Ta DWD) in Freiburg, Germany



Source: Andreas Matzarakis, Meteorologisches Institut, Universität Freiburg, Freiburg, Germany, personal communication, 2003.

Fig. 25 shows the relationship between indoor and outdoor temperatures in a free-running three-storey building in summer in Freiburg, Germany. At night and during most of the day, temperatures in the buildings (third floor) are higher than outside. Nevertheless, peak temperatures outside on warm days (Ta > 25 °C) are higher than inside on the third floor. Another important aspect is that the temperatures on the third floor are about 4 °C higher than the temperatures on the first floor, and temperatures there are often cooler than outside. Many well designed buildings have quite a different temperature profile and are consistently cooler than outdoors on summer days.

5.5.2. Adaptive behaviour, energy and sustainable buildings

Humans exhibit a physiological response to thermal conditions, but clothing, buildings and many other social, economic, contextual and behavioural factors contribute to heat balance. In addition, thermal comfort (described as a state of mind) is in fact a mental and not a physiological construct.

In practice, people do not react passively to the conditions buildings provide but interact actively with the buildings they occupy. Two typical types of interaction are:

- adapting themselves (by such means as clothing, activity, posture, shivering or sweating) to the conditions they experience; and

- adjusting the conditions provided (such as by means of windows, blinds, heating or air-conditioning) to suit the occupants.

These actions have to be taken within a social, economic and cultural context, but they mean that, in most cases, people learn to be comfortable in their usual environment. Provided that the changes to that environment are sufficiently slow and the cultural and social constraints are not too restrictive, people can also make themselves comfortable in a wide variety of environments.

In more extreme environments, the need to keep warm (or cool) may use large amounts of energy. Buildings that are poorly designed can add to this burden through poor insulation, poor planning, over-glazing and other aspects. They can also cause occupants to use electric lighting and other equipment more than necessary. Buildings account for about 50% of the energy used in industrialized countries, and much of this is used in building services, especially in air-conditioned buildings, where much of the energy is used as electricity.

Using air-conditioning to overcome the heat stress caused by global warming constitutes a potentially dangerous positive feedback loop. Air-conditioning leads to more energy use, which results in more carbon dioxide being emitted (unless energy that does not cause carbon dioxide emission, such as solar or wind energy, is used), which causes more warming, which requires more air-conditioning. Being consistent and sustainable means that heat stress should be avoided without relying on high-energy solutions. With good design, buildings can provide conditions that occupants find acceptable or even positively enjoyable!

This requires that buildings:

- work with and not against climate and people’s natural ability to adapt;

- enable occupants to exert control over their environment; and

- provide constant and consistent indoor conditions that occupants can learn to enjoy.

In addition, people (or their managers) must not constrain people’s adaptive opportunities by restricting access to controls, variability in clothing and activity etc. and work with building managers to ensure the optimal working of the buildings.

Finally, replacing fossil fuels by renewable energy, especially building-integrated electricity generation, means that future buildings may be developed that are energy-neutral or even net contributors to the energy economy.

5.5.3. Building design

Buildings are designed to have a long lifetime. Climate change (such as the increasing numbers of extremely hot days), changing lifestyles and new technologies all have implications for building design. With respect to climate change, designing comfortable, energy-efficient and safe buildings is a priority. In particular, the design should aim to limit both the frequency of occurrence of high-temperature episodes inside the building and their indoor intensity and duration. Traditional building designs have evolved in harmony with the environment and usually provide adequate protection against the heat. In recent decades, rapid urbanization seems to have led to an increase in poor building design in many cities. Thus, populations in these dwellings are less adapted and perhaps more vulnerable to heat episodes.

Technological advancements have permitted the design of structures that emphasize engineered approaches to interior climate control. As a result, modern structures often do not reflect local climates, needlessly consume large amounts of energy and assume a uniform level of comfort for the building occupants. Architectural design can prevent buildings from warming up and thereby ensure a comfortable indoor environment without using energy-intensive air-conditioning. Table 18 describes techniques that can reduce indoor heat stress in hot and dry environments. Natural cooling techniques should be favoured in all future building or retrofitting to old buildings. The effective use of simple natural cooling strategies in hot climate building design can reduce internal temperatures both day and night (WHO, 1990).

Inside the building, climate is controlled by (Givoni, 1986):

- the geometrical configuration of the building;

- the orientation of the building;

- the size and location of windows;

- the properties of the building materials; and

- the colours of external surfaces.

The following building design objectives are suggested (Givoni, 1986):

1. minimize solar heating of the building during the hot season;
2. minimize the rate of indoor temperature elevation in summer during daytime;
3. maximize the rate of cooling of the indoor temperature in summer during evening and ensure indoor comfort at night;
4. utilize natural energy for passive cooling in summer;
5. minimize the heat loss of the building in winter; and
6. utilize passive solar energy systems for heating in winter.

These building objectives can be achieved by the architectural features listed in Table 18. For example, constructing more compact houses adversely affects objective 3 but positively affects objectives 1, 2 and 5.

TABLE 18. ARCHITECTURAL FEATURES AFFECTING THE PERFORMANCE OF A BUILDING TO REDUCE THERMAL STRESS

Architectural feature	Effect or building strategies	Negative effects on objectives	Positive effects on objectives
Building layout	The more compact the house, the smaller the surface area of the walls for a given floor area.	3, 2 (lights)	1, 2, 5
	The more compact the house, the more electric lighting needed.		
	Effects on energy use and heat release.		
	A passive solar building may use its southern wall and windows as the solar collection elements.	1, 2, 5	3, 6
	Buildings elongated along the east–west axis will be more energy efficient than a square building despite their larger wall surface area.		
Building orientation and shading objectives	Highest intensities of the impinging solar radiation:		1, 2, 5, 6
	• summer: eastern and western walls		
	• winter: southern wall.		
	A north–south orientation for the main façades and windows.		
Window size and location	Natural ventilation: hot, dry regions require small windows.	3, 6	1, 2, 5
Colours of the building	The difference in maximum surface temperature between a white and a black roof in a desert can be about 40 °C. The heat gain depends on the insulation.	6	1, 2
	White roofs are best.		
Thermal properties of building materials	High thermal insulation coupled with effective shading.	3	1, 2, 5
	High heat capacity.	3	1, 2, 5
Building height (Nieuwolt, 1986)	Only for humid regions: construction of tall buildings because wind speed increases with elevation while temperature and humidity tend to decrease.	5	3, 4
Kitchens, water heaters and bathrooms on the leeward side (Nieuwolt, 1986)	Heat can be rapidly removed by draught.	5	2, 3

Sources: adapted from Givoni (1986) and Nieuwolt (1986).

5.5.4. Air-conditioning

Air-conditioning (space cooling) in homes, at working places and in public and commercial buildings provides a cooled environment and reduces people's exposure to high temperature. Evidence from the United States indicates that air-conditioning seems to be an effective intervention in preventing heat stroke and heat-related illness during a heat-wave (Marmor, 1975; Kiernan, 1996; Semenza et al., 1996). More than 80% of homes in the United States have air-conditioning. Air-conditioning has significantly reduced the death rate during hot weather: by 42% for those with central air-conditioning. Single-room air-conditioning did not confer a substantial benefit over no air-conditioning (Rogot et al., 1992), and moving from unventilated, indoor locations to air-conditioning reduced the mortality risk of individuals by a factor of about 5–6 during the 1995 Chicago heat-wave (Chan et al., 2001; Semenza et al., 1996). A study the Energy Information Agency carried out in the United States in 2003 found that the mortality decline from the 1980s to the 1990s was linked with increased air-conditioning penetration. In addition, air-conditioning reduces the penetration of (polluted) outdoor air to indoor air and ventilation exchange. Associations between hospital admissions and airborne particles in 14 United States cities were significantly lower in cities with a higher prevalence of air-conditioning (Janssen et al., 2002).

Nevertheless, air-conditioning has disadvantages, being associated with negative effects that directly or indirectly affect human health. Air-conditioning increases energy consumption, which increases greenhouse gas emissions if no carbon dioxide-neutral technology is used for energy production. Power plants may fail especially during heat-waves, when the energy demand rises and they emit pollutants, which endangers air quality. Air-cooling devices spread microbes, such as that causing Legionnaire's disease (Merz, 1993), and inadequate maintenance puts the indoor air quality at risk. The sick-building syndrome is more prevalent in air-conditioned buildings. Auliciems & De Dear (1986) conducted a survey about the perceived disadvantages of air-conditioning in offices in Darwin, Australia. The perceived disadvantages included health issues such as general health problems, excessively cold indoor environments and great thermal gradients between indoor and outdoors. The perceived advantages were coolness and comfort and productivity, concentration and ease of paperwork. It is not very surprising that the factors ranking highest in the perceived disadvantages of home air-conditioning were the costs followed by health issues. The perceived advantages were better sleep and comfort and relief.

The energy use of air-conditioning can also be reduced by letting the indoor temperature drift with outdoor temperature, thus reducing the amount of cooling the air-conditioning system has to provide. Air-conditioning often counteracts good building design because architects can use air-conditioning to avoid responsibility for providing comfort for the building occupants in more natural ways.

Anthropogenic heat production worsens the urban heat island effect: Wilby (2003) assumes that the increasing trend in the nocturnal urban heat island in London in spring, summer and autumn is caused in part by the greater use of air-conditioning in recent decades. The need to use extra energy to counteract the urban heat island disproportionally affects resource-constrained people, who often live in urban areas and thus face the heat island phenomenon even more.

However, quantifying the role of air-conditioning in reducing mortality is difficult because of multiple confounding factors. Davis et al. (2003) pose interesting questions, such as whether air-conditioning is indeed the main cause of the observed declines. Once air-conditioning penetration approaches market saturation, will heat continue to significantly influence mortality in the United States? Will air-conditioning be available to all socioeconomic classes? Will future changes in energy markets and pricing inadvertently force some people to put their health at risk during heat-waves? Can poorer people afford to buy and operate air-conditioning? What is the role of energy efficiency standards and changing policies?

Providing air-conditioned public spaces (cooling centres) and offices and improving social conditions and assistance to the people at risk may reduce disparities in the effects of heat on mortality (O'Neill, 2003).

5.6. Potential impact of climate change on urban climate

5.6.1. Introduction

Increasing urbanization and associated changes in land use significantly modify the local and regional climate. Large-scale atmospheric parameters that are relevant for energy budgets are likely to change as the climate warms. Such changes will affect the bioclimatic situation in urban areas (Wagner, 1994, 1999).

Climate change is anticipated to increase the frequency of days above a temperature threshold because even small increases in average temperature can result in large shifts in the frequency of extremes. However, whether climate change will be associated with an increase in the magnitude of the urban heat island effect is uncertain. An increase in baseline temperatures may increase the total thermal burden on the city but not necessarily alter the urban–rural difference (Oke, 1997). The magnitude of the heat island is modulated by the prevailing synoptic weather. If the regional climate of a city shifts to more anticyclonic conditions, the heat island may be enhanced; otherwise, if the shift is to more cyclonic conditions, the urban-rural temperature difference may decrease (Oke, 1997).

Assessing the possible impact of future climate change on urban climate is difficult. Current projections of climate change using general circulation models do not provide output at a suitable spatial resolution. Further, information on extreme values is required as reliable input to any kind of local study (Dalfes, 1991). The impact of global climate change on urban areas can be categorized in two sets (Farago, 1991):

- the impact on climatic features; and
- the impact on the chemical composition of the urban air.

Assessing the impact of climate change on urban climate in the future requires the following investigations (Gross, 1996):

- assessing the baseline climate;
- determining the regional impact of global climate change;
- taking into account the specific geographical situation of the city; and
- taking into account nonclimatic factors, such as technological innovations, motorized transport, behavioural aspects and cultural trends.

5.6.2. Projections of the impact of climate change on European cities

A few studies have been undertaken that have applied climate scenarios to specific cities to estimate future changes in bioclimatic indices (Annex 4).

The output of general circulation models needs to be downscaled for the assessment of the urban climate. Wagner (1994) nested a regional climate model to get a resolution suitable for cities. The error in the output of general circulation models is often greater than 20%, which also increases the uncertainty of the urban heat island estimates. Further, these studies do not consider future changes in non-climatic factors (such as population growth, building density and energy consumption) and impact on the urban climate.

5.6.3. Case study: Tel Aviv

A research project was carried out on the climate of Tel Aviv, Israel. The heat island of the city has been identified and the heat stress has been calculated. It was decided to examine what would happen if warming affects the urban area of Tel Aviv according to expected forecasts of global warming or because of increasing density, compactness and activities. A progressive change of 1 °C was taken into consideration. In July 1990, the heat stress in the core of the Tel Aviv heat island was in the upper "moderate" range and slightly lower close to the beach (Fig. 26). Raising the temperature each time by 1 °C to the upper expected limit of 4 °C causes drastic changes in heat stress (Fig. 26). From the level of "moderate", heat stress in Tel Aviv will increase and reach the level of "severe", with high absolute values, like those of the harshest climatic zones of Israel (Bitan, 2003).

Heat stress is defined based on the discomfort index (DI), which has the following formula (Bitan & Potcher, 1995).

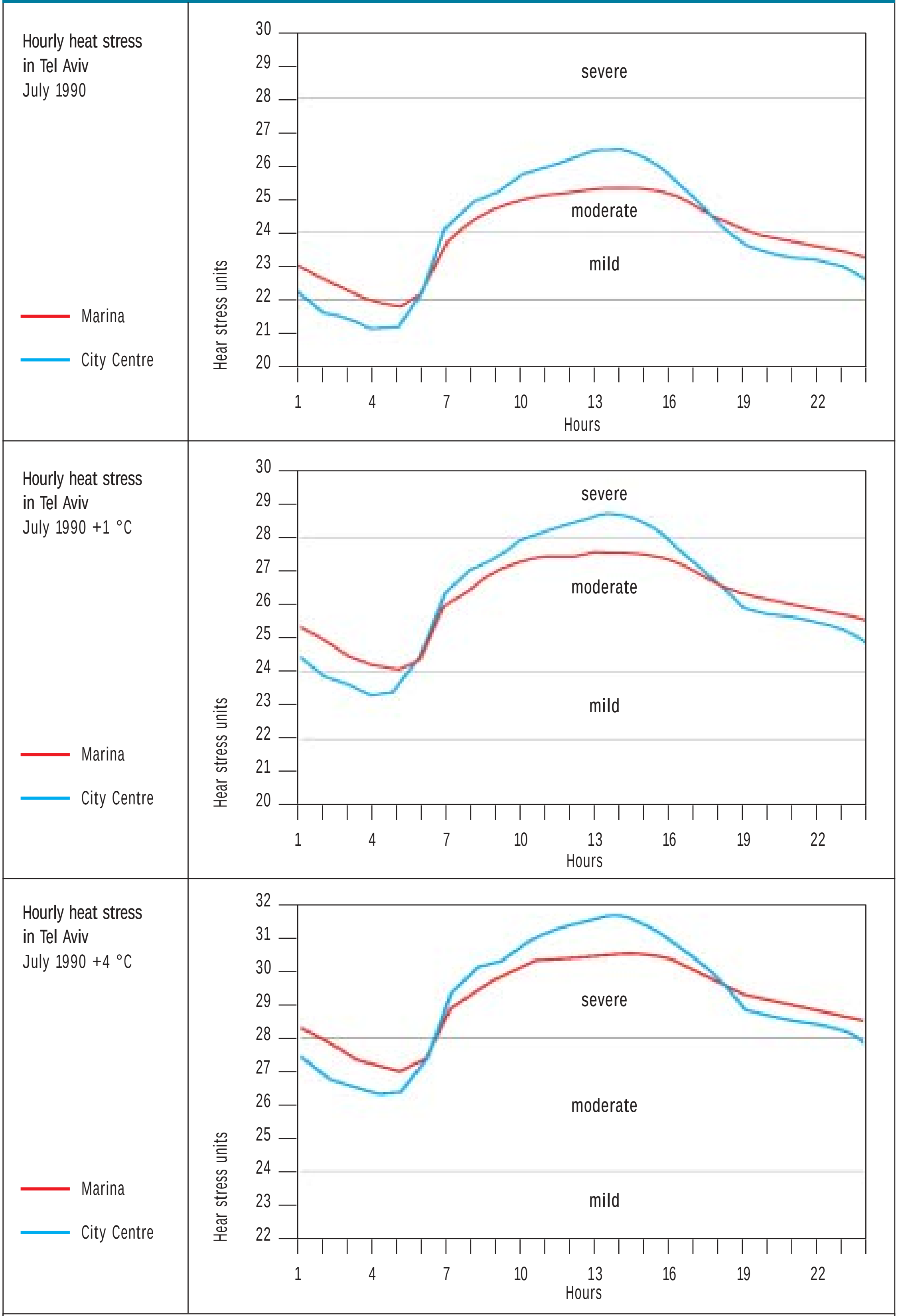
DI = ”0.5 * (dry bulb temperature + wet bulb temperature)

The following classification is used for mild, moderate and severe heat stress:

Less than 22.0 °C	No heat stress
22.0–23.9 °C	Mild heat stress
24.0–27.9 °C	Moderate heat stress
28.0 °C or more	Severe heat stress

As illustrated by the example of Tel Aviv, intensification of heat stress will result in an increase in air-conditioning, which means the need for more energy, mainly produced by fossil resources. Beside the increased carbon dioxide emission and its impact on greenhouse effect, it will cause the addition of the direct surplus of sensible heat energy into the urban atmosphere (Bitan, 2003).

Fig. 26. Hourly heat stress in Tel Aviv



Source: Bitan (2003).

5.7. Discussion and recommendations

Appropriate planning and building measures can reduce the impact of the urban heat island on human health. Green spaces can prevent cities from heating up so much, and adapted building design allows gains in thermal comfort conditions inside buildings without artificial air-conditioning. At night, indoor conditions are more relevant for thermal comfort and recreation and sleep depth. During the day, however, indoor as well as outdoor conditions affect thermal comfort.

Assessing the contribution of individual planning measures in reducing outdoor heat stress is challenge. Although spatial bioclimatic information helps in assessing the different heat stress levels in different urban structures, assessing the heat load to which an individual is exposed during a specific period of time is difficult.

Projecting the thermal stress in urban areas under changed climate conditions is very difficult. Climate scenarios must be downscaled to assess the regional climate changes, and then the impact of these regional changes must be linked to the urban climate. As the urban climate is not only influenced by the regional climate but also by changes in population, building density, energy use and other factors, changes in all these other factors have to be addressed to assess the future urban climate. Heat-waves will be more intense and more frequent. Studies modelling the urban thermal environment and climate change indicate that the heat load on individuals will increase.

5.7.1. Discussion: urban heat islands

Heat islands are the most well known phenomenon of the urban climate. During heat-waves, the urban heat island puts additional heat load on human beings. Urban heat islands affect human health, although the impact of any reduction of the heat island may be minimal. However, not all urban effects are negative. In winter, the urban heat island might be beneficial by saving heating energy. In addition, a city provides a variety of microclimates that allow individuals to choose their preferred environment. The thermal differences within the various urban microclimates might be greater than the difference between the (spatial means of the) urban climate and the rural climate. The larger a city, the more pronounced the urban heat island and the higher the risk of heat stress in summer.

Urban planners should be aware of the health relevance of the urban climate and how urban planning affects urban climate. Appropriate urban planning should have the following objectives:

- reducing the heat island in summer;
- reducing the heat load on buildings;
- diminishing the problem of high night-time indoor temperature; and
- taking climate change into account in planning new districts and buildings and in setting up new regulations on building and urban development.

Several measures can be taken to reduce the heat load to which an individual is exposed in a city, such as planting trees or building houses with arcades that provide shade. At night, when solar radiation does not play a role, cities can cool down. Planners should therefore consider allowing cool air from the surroundings to penetrate the city by maintaining ventilation paths. However, redesigning the city on a larger scale is usually generally illusionary, and planning measures are usually restricted to a small part of the city.

5.7.1.2. How can measures be implemented?

European Union countries have different strategies for implementing measures to reduce the urban heat island. Climate design should be included in town planning and building code legislation, such as in Germany. For example, building regulations might include planning measures that reduce the urban heat island. Examples of planning aspects that are regulated in Germany are the height of the buildings, the building density and the kind of trees to be planted along the streets. However, this approach may not be able to be extended to other European countries.

Building regulations should not only reduce thermal stress but also reduce air pollution and try to increase the quality of life in the city. Incorporating all these aspects makes planning a difficult and complex problem. However, appropriate planning and ensuring green spaces provide additional benefits, including increasing a city's attractiveness for business and tourism.

Building regulations should not only be valid for new built-up areas but should also be incorporated when parts of the city undergo renovation. In addition, planners must be able to include the climate-relevant building regulations in the planning process. This, in turn, means that planners and architects must be trained in climate-relevant planning and building. Awareness must not only be increased for planners and architects but also for the local administration and the policy-makers who are in charge of establishing the regulations and ensuring compliance. Educational material must be written in the language of the different target groups (policy-makers, local administrators, planners and architects).

Quantifying the climatic effects of different planning options requires models and experimental results. Modelling shows the benefits and costs of even small changes in the urban structure. Such models need a broad climatic data base to become an operational tool for urban planners.

5.7.2. Discussion: indoor thermal comfort

One adaptation option to reduce heat load in a changing climate is to maintain or increase indoor thermal comfort. Several points should be considered to maximize indoor thermal comfort. One is that climate-adapted building and energy-efficient design should be stressed over air-conditioning. This point gains importance in case of an energy crisis. Conversion from an active to a passive energy building will be difficult and costly if the price of energy increases markedly. Air-conditioning should therefore not be promoted before other options in building design are explored, including shading, glazing, orientation and thermally induced natural ventilation. Such options include (see also section 5.5.3):

- shading of the building, which reduces the impact of solar radiation in summer;
- trees and plants to shade walls and windows in summer and other shading devices for windows;
- highly insulative building materials;
- bright colours on all surfaces;
- orientation and window size; and
- ventilation.

Some of these building options that are beneficial in summer might detrimentally affect winter indoor climate and lead to higher energy consumption in winter (for example, brightly coloured buildings reduce energy gain in winter). Thus, summer benefits and winter costs should be carefully balanced, and all these planning strategies should be well implemented. As climate characteristics differ in northern and southern Europe, the strategies that reduce indoor thermal stress should be related to climate. Strategies that are only beneficial in southern Europe because the winter is mild might be detrimental in winter in northern Europe.

Architects must be educated so that they can assess what strategies to use to optimize thermal comfort with very little additional heating or cooling energy. Not only the architects must be educated. Education campaigns must also target the general public, telling them about the proper use of windows and shading devices or that avoiding cooking during hot periods is beneficial. Both education campaigns (architects and the public) must focus on explaining that especially high night-time temperatures detrimentally affect health.

5.7.3. Lessons learned

Hot countries already have strategies to reduce the impact of heat indoors and outdoors in cities. Those strategies now have to be transferred and adapted to the countries of central and northern Europe. Including local requirements in these strategies is important. Other important lessons can be learned from poor urban design. Ensuring that urban planning and building designs take climatic aspects into account requires incorporating these climatic aspects in building codes in a more detailed way such is done in Germany.

In the United States, the cities with the best urban planning strategies are those with the highest environmental pressure to protect the citizens from natural hazards. Unfortunately, heat-waves are often not seen as an environmental hazard that kills. Measures to reduce urban heat islands in some cities have been only side-effects of other measures or intentions. In Chicago, a tree-planting project was started because of the need to protect the power supply by reducing urban temperatures, not to protect human health. And in Italy a political party planted many trees during an election campaign.

Green spaces can be promoted in cities by including them in building regulations or subsidizing the planting of trees and other plants. In Belgium, for example, people are given subsidies to build a green roof to retain water. Again, the purpose is not to reduce the urban heat island but to reduce flooding, but with a side-effect for the urban climate.

6. CONCLUSIONS AND RECOMMENDATIONS

The heat-wave of summer 2003 has shown that Europe is vulnerable to the effects of heat-waves on human health. A number of concomitant factors contributed to the high excess mortality in some countries, such as the unexpected length and intensity of the heat-wave, the lack of preparedness of health care and social systems for such an event, the lack of intervention plans and the lack of effective technical solutions.

There are gaps in understanding the effectiveness of early warnings and alerts, but gathering better insight on how best to set up such systems and which effective intervention strategies to recommend at the European level will be difficult until more systems have been implemented and evaluated.

The recommendations and conclusions of this report target the research community, public health agencies and meteorological services and sectors involved in housing and urban planning and design.

6.1. The research community

The following need to be better understood:

- the role of minimum, maximum or daily mean thermal conditions on heat-related mortality and morbidity, which is still unclear and difficult to distinguish because the meteorological parameters are closely correlated;

- the effectiveness of public health measures and interventions in the European context; and

- the responses of elderly people and other vulnerable groups to heat:

    – physiological effects;

    – the role of behaviour in responding to higher ambient temperatures;

    – the development of appropriate heat advice messages.

Although much research has been performed in urban climatology, future research needs to address some questions.

- The potential of single planning measures and strategies in reducing the urban heat island and the heat load and benefiting individuals needs to be evaluated, including how this affects health and the costs and benefits.

- More detailed methods and models need to be developed to assess indoor and outdoor thermal stress under changed climatic conditions.

- How does outdoor climate affect thermal comfort indoors and thereby health?

- Fig. 26 shows that indoor temperatures are higher on the upper floors than downstairs. An interesting research project would therefore be to investigate individual housing and exposure characteristics of people who get heat illnesses. The hypothesis is that a relatively high percentage of these people live on upper floors or under the roofs of poorly insulated houses.

- The relationships between outdoor temperatures, urban heat islands and the individual risk of heat-related mortality needs to be investigated further.

- More research has to be done on how climate and global change will affect the thermal environment of cities:
  - – more detailed regional and local climate models – downscaling to the urban level;
  - – including more detailed climate simulation in integrated assessment models; and
  - – developing special urban scenarios.

6.2. Public health agencies and meteorological services

Based on the experience of summer 2003, countries and cities need to start thinking about whether they should develop heat health warning systems and intervention plans. Several recommendations can be made for implementing such systems based on the experiences of existing heat health warning systems.

Heat health warning systems can be set up in a range of European cities, once heat-waves are recognized as presenting a potential threat to human health and the necessary collaboration between meteorological services and public health agencies is started. Systems need to be shared under joint responsibility. The national and local levels might further discuss which other institutions should be involved to ensure proper intervention planning. Funding mechanisms need to be ensured throughout the whole process.

Because climate and culture differ within Europe, heat health warning systems should be developed to fit the local setting. One very important aspect is to adjust information flow and intervention measures to the local needs and the available infrastructure. However, having some standardization across systems to facilitate comparison and knowledge transfer would be beneficial. Regional coherence is required so that warnings are consistent from one town to the next.

The methods used for developing the warnings need to reflect the physiological relevance of the thermal environment. The warning indicator must be based on data that are easily available for the region of interest. Independent of the heat-wave indicator chosen, more than one level of warning is needed. The thresholds of the warning indicator should allow for adaptation to be included, combining a relative (local) and an absolute component. This ensures that, even under nonstationary climatic conditions (climate change and climate variability), thresholds and warning indicators will not have to be changed.

Any heat advice message should be adapted to the social and behavioural context of the target population, especially for northern, southern and eastern Europe. Different heat advice messages should be given to different target groups. As the advice given during a heat-wave should be place specific and include various cultural aspects, more detailed advice will be needed for the populations of northern Europe that are not used to heat than for populations that are used to coping with heat.

The warnings should target the whole population and especially groups that are more vulnerable and the institutions and organizations that are responsible for their welfare. In addition, the warnings should also be sent to institutions, such as health service providers, general practitioners, organizers of sport events and care workers. Warnings should also be communicated to electricity providers to avoid power failures.

During periods of severe heat, not only heat itself affects human health but also ultraviolet radiation, ground-level ozone and other air pollutants that are directly or indirectly related to the weather conditions. To avoid many separate warnings and advisories, the advice about heat should be linked to advice about protection from ultraviolet radiation, and, if appropriate, air pollution. Educational strategies are very important in raising the awareness of the hazard so that the population is prepared when a heat-wave occurs.

Current evidence indicates that government services and health agencies are poorly prepared for severe heat-waves. Governments do not perceive heat as a problem. Because of the predominantly simple measures used to mitigate heat effects, the government services are underestimating the health risks. Heat-waves are often accompanied by power failures and failures in water supply. Heat-waves should therefore be included in emergency planning at the local and national level.

6.3. Long-term intervention strategies

These measures are short-term strategies to enable populations to cope with acute problems, but other strategies to cope with climate change might be necessary in the long term. These strategies are outside the scope of the public health services, but an accurate health impact assessment of these strategies might become necessary.

Hot countries already have strategies to reduce the impact of heat indoors and outdoors in cities. Those strategies now have to be transferred and adapted to the countries of central and northern Europe. Including local requirements in these strategies is important. Other important lessons can be learned from poor urban design. Ensuring that urban planning and building designs take climatic aspects into account requires incorporating these climatic aspects in building codes in a more detailed way such is done in Germany.

- *Build and design for future climate.* In Europe, new buildings are planned to last several decades. The future climate should therefore be taken into account in constructing new buildings and planning new parts of the city to provide as much thermal comfort as possible today and in the future.

- *Emphasize conserving energy.* Use renewable energy (solar energy does not affect the urban heat island in the short term) for heating and cooling purposes. Fossil fuels release carbon dioxide, thus increasing the greenhouse effect.

- *Reduce the number of motor vehicles.* Every motor vehicle is a source of anthropogenic heat and thus worsens the urban heat island and urban climate.

- *Develop information systems on the urban climate.*

- *Maintain high natural levels of heat acclimatization.* This can be achieved by an active lifestyle (fitness) with properly adjusted climatic exposure (behaviour and climate) (Havenith, 2001a).

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Annex 1.

Programme of the cCASHh Workshop on Vulnerability to Thermal Stresses, 5–7 May 2003, Freiburg, Germany

MONDAY, 5 MAY 2003

9:00–9:15	Welcome (*Gerd Jendritzky & Bettina Menne*)
9:15–9:30	Short introduction of the participants
9:30–10:00	Objectives of the research and the workshop (*Bettina Menne*)
10:00–10:30	The physiology of heat-related illness and mortality (*George Havenith*)
10:30–11:00	The epidemiology of heat-related illness and mortality (*Sari Kovats*)
11:00–11:15	*Coffee break*

SESSION I. Heat health warning systems – methods

11:15–11:30	Survey of heat health warning systems in Europe (*Christina Koppe*)
11:30–12:00	Heat health warning systems: overview (*Scott Sheridan*)
12:00–12:20	Evaluation of the Rome heat health warning system (*Paola Michelozzi*)
12:20–12:40	Evaluation of the Lisbon heat health warning system (*Paulo Jorge Nogueira*)
12:40–13:00	The Assessment and Prevention of Acute Health Effects of Weather Conditions in Europe (PHEWE) project (*Paola Michelozzi & Glenn McGregor*)
13:00–14:00	*Lunch*

SESSION II. Heat health warning systems - intervention measures and evaluation

14:00–14:15	Madrid study *(César López Santiago & Julio Díaz Jiménez)*
14:15–14:45	The Philadelphia system – value of information study *(Kristie L. Ebi)*
14:45–17:30	Group work 1. What are best methods for identifying “heat-waves”? 2. When should a heat health warning system be set up? 3. Who would be the target of the heat health warning system? 4. How can a heat health warning system be best implemented? 5. Which problems exist after a warning is issued? 6. How can the system been best evaluated? *Coffee break during the group work*
Evening:	*Dinner at Restaurant Dattler*

TUESDAY, 6 MAY 2003

9:00–10:30	Presentations of the results of the group work
10:30–10:45	*Coffee Break*

SESSION III. Urban planning

10:45–11:15	The urban heat island – its negative impact on human comfort and measures to be taken to reduce its effects *(Arieh Bitan)*
11:15–11:45	Indoor climate: relationship between indoor thermal comfort and buildings from a multi-disciplinary point of view *(Fergus Nicol)*
11:45–12:15	UBIKLIM urban bioclimate model *(Gerd Jendritzky)*
12:15–12:45	Planning measures *(Jürgen Baumüller)*
12:45–13:45	*Lunch*
13:45–16.30	Group work 1. Which intervention strategies are available and which are the most effective? 2. Are there lessons learned from interventions that have been implemented elsewhere? 3. If so, what can be recommended?
	Coffee break during the group work
16:30–17:30	Presentation of the results of the group work
19:00	*Reception hosted by the City of Freiburg*

WEDNESDAY, 7 MAY 2003

08:45–09:15	Integrated assessment model: thermal stress *(Michael van Lieshout)*
09:15–09:45	Evaluation of adaptation measures – methods *(Aline Chiabai)*
09:45–10:00	Adaptation to thermal stress – lessons learned for the conceptual framework *(Hans-Martin Füssel)*
10:00–11:00	Final discussion on adaptation strategies
11:00–11:15	*Coffee break*
11:15–12:30	Development and review of the recommendations
12:30–13:00	Next steps

Annex 2.

Questionnaire on extreme thermal events and health warning systems

This questionnaire was sent to 45 countries in the WHO European Region.

PART 1: GENERAL INFORMATION

1. Name and address of your institution:
2. Who can we contact if we have further questions regarding this issue?
3. Are you interested in the outcome of this survey
   (it will be sent to the contact person given above)?

PART 2: EXTREME THERMAL EVENTS

1. Does an official definition of a "heat-wave" exist in your country?
   a) If yes, would you please write down this definition:
   b) On which spatial scale is the heat-wave determined?

☐ "city-scale" ☐ regional scale ☐ national scale

☐ other: ....

2. Does an official definition of a "cold-spell" exist in your country?
   a) If yes, can you please write down this definition:
   b) On which spatial scale is the cold-spell determined?

☐ "city-scale" ☐ regional scale ☐ national scale

☐ other: ....

PART 3: HEAT WARNING SYSTEMS

1. Does any kind of warning system with respect to thermal extreme events exist in your country?
   a) If yes, does this system imply hot weather warnings?
   If yes,
   - What is the criterion for releasing a warning?
   - What is the criterion for closing the warning?
   - For which spatial scale is the warning released?

☐ "city-scale" ☐ regional scale ☐ national scale

☐ other: ....

   - Who is the target group for the warning (such as health authorities, public)?
   - What is the organizational procedure of the warning (such as which is the medium of the warning, how much time is the warning given in advance)?
   - What is the aim of the warning system?
   - Are there any intervention plans for when a warning is issued?
   - If yes, can you please describe this intervention plan in a few words:
   - Who implements the plan? Would you please tell us the name of a contact person at these "institutions"? (For example, in the US, the local fire departments are often involved in implementing heat-wave warnings.)

   b) Please try to estimate the costs of the implementation of the warning system:*

.... (EUR)

   c) Please try to estimate the benefits of the implementation of the warning systems:*

.... (EUR)

.... (number of lives saved)

* If you are not able to answer these questions, do you know someone we can contact with respect to this problem?

   d) If no heat-warnings exist, is your agency thinking about establishing a hot weather warning system?

2. Which are other agencies to contact that may have useful information with respect to thermal extreme events and health warning systems?

Annex 3.

Current status of heat health warning systems in Europe

The following countries responded to the survey on heat health warning systems (Annex 2) or were identified as having heat health warning systems.

TABLE 1. COUNTRIES WITH HEAT HEALTH WARNING SYSTEMS

Country	Response	Type of heat health warning system+		
		I	II	III
Albania				
Armenia				
Austria	X			
Azerbaijan	X	X*		
Belarus	X		X*	
Belgium	X			
Bosnia and Herzegovina				
Bulgaria				
Croatia	X			
Cyprus	X			
Czech Republic	X	X		
Denmark	X			
Estonia	X	X*		
Finland	X			
France	X			
Georgia	X			
Germany	X			
Greece	X		X*	
Hungary	X			
Iceland	X			
Ireland	X			
Israel	X			
Italy (Rome)				X
Kazakhstan	X		X*	
Latvia	X	X*		
Lithuania	X			
Luxembourg	X			
Malta	X		X*	
Monaco				
Netherlands	X			
Norway	X			
Poland				
Portugal (district of Lisbon)	X			X
Republic of Moldova	X			
Romania	X	X*		
Serbia and Montenegro	X		X*	

TABLE 1. CONTD

Country	Response	Type of heat health warning system+		
		I	II	III
Slovakia	X			
Slovenia	X	X*		
Spain	X		X*	
Sweden	X			
Switzerland	X			
The former Yugoslav Republic of Macedonia	X		X*	
Turkey	X		X*	
Ukraine				
United Kingdom**	X			

Thirty-seven of the forty-five countries surveyed responded to the questionnaire (82%).

\+ See Table A1 for definitions of types of heat health warning systems.
* Situations that adversely affect human health are not explicitly identified.
** The United Kingdom has a system that provides daily information for hospitals based on the weather situation but no specific heat health warning system.

TABLE 2. DEFINITIONS OF TYPES OF HEAT HEALTH WARNING SYSTEMS

Type 1	Type 2	Type 3
• Identification of weather situations that adversely affect health • Monitoring of the weather forecasts • Mechanisms by which general warnings are issued when an adverse weather situation is forecast		
	• Communication of the warning either to the general public and/or • to health agencies	
		• The warning triggers community-based public health interventions

Annex 4.

Projection of climate change in European cities

City	Scenario	Methods	Results	Comments	Reference
Berlin	ECHAM1 simulation until 2100 Control run (carbon dioxide concentrations remain at 1985 level)	Regional climate model FITNAH (high resolution (100 m by 100 m grid), three-dimensional simulation of urban mesoclimate) was nested	*Changes in mean temperature* Between 2040 and 2070, air temperature will increase by 2 °C without changes in the building structure and by 3 °C to 4 °C after Potsdammer Platz and Spreebogen are covered with buildings Further, wind speed will decrease by 80% based on the reference climate *Changes in the probability of extreme events* Increase in number, duration and intensity of heat-waves *Changes in the mean winter temperature* Warming (2080) by 2.5 °C compared with reference run (without looking at changes in the city structure)		Wagner (1994)
Berlin			*Changes in the probability of extreme events* Three times more hot days (Tmax > 30 °C) in 2080 and nine times more very hot days (Tmax > 39 °C) than in 1985		Gross (1996)

City	Scenario	Methods	Results	Comments	Reference
Berlin	Model: ECHAM1/LSG; time horizon (2050–2079)	Monte Carlo simulations using a first-order autoregressive model	1.7 °C increase in mean air temperature, 19% increase in standard deviation, slight increase in first-order autocorrelation coefficient *Changes in the probability of extreme events in July* An extreme event is defined as five consecutive daily maximum temperatures: • exceeding 30 °C: repetition rates will decrease from 8 years to 3 years • exceeding 33 °C: repetition rates will decrease from 47 years to 8 years		Wagner (1999)
Vienna	Historical data from 1873 to 1990 are used to generate scenarios of changing climate and to calculate the impact of this variation on thermal comfort General circulation model of the Goddard Institute for Space Studies for Europe (doubling of the CO2 concentration)		Temperature increase of the general circulation model of the Goddard Institute for Space Studies is equal to the 10 warmest months between 1873 and 1990 *Changes in the probability of extreme events* Number of days with heat stress in July will increase from 1.8 to 5.2 Number of days with cold stress in January will be reduced from 21 to 7.5	Limitations: temporal analogue only works if other meteorological parameters influencing heat stress remain the same	Koch et al. (1992)

Heat stress is defined based on an human energy balance model. Discomfort occurs if one of the following criteria are fulfilled: mean skin temperature less than 29°C or higher than 35°C; heat gain caused by shivering > 0; sweat rate > 1.5 times the mean sweat rate in case of comfort; skin wetness > 25%. Clothing is varied by ± 0.5 clo (baseline clothing in July 1.0 clo). Heat (cold) stress occurs if the model shows discomfort after improving for clothing.

City	Scenario	Methods	Results				Comments	Reference
Istanbul		Assumed change in temperature: 5 °C (months July and August, shift in the mean and not in the variance) Probability density function (15 years of data) was shifted by the 5 °C assumed change in temperature	*Changes in the probability of extreme events* Probability of getting daily mean temperatures over 30 °C: current climate: ~ 0 future: 8 out of 61 (~ 8 per year)				Limitations: No change in the variance was considered Coarse resolution of global circulation model Predicted population changes (1990: 7.4 million to 15.5 million in 2040) were not considered	Dalfes (1991)
London	HadCM3 (1961–2099) UKCIP02	Regression model based on the period 1961–1990 Predictors: near surface wind strength westerly wind strength vorticity relative humidity 850 hPa geopotential height		ΔUHI (°C)	ΔUKCIP02 (°C)	Δf (days)	ΔUHI: changes in the annual nocturnal urban heat island intensity; changes are in addition to regional warming ΔUKCIP02: regional temperature changes projected by the UKCIP02 Δf: changes in the frequency of intense (>4 °C) urban heat island days	Wilby (2003)
	Medium-high emissions		2020s	0.07	0.5–1.0	5	All changes with respect to 1961–1990 average (urban heat island = 1.8 °C)	
			2050s	0.16	2.0–2.5	9		
			2080s	0.26	3.5–4.0	15		
	Medium-low emissions		2020s	0.03	0.5–1.0	3		
			2050s	0.17	1.5–2.0	10		
			2080s	0.19	2.5–3.0	11		

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