Heat Waves, Urban Climate and Human Health

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1 Global Climate Change and Heat Waves

The European heat wave of 2003 was an outstanding weather event. The months of June and August have been nearly everywhere in Germany the warmest months since the start of registrations in 1901. The registered mean air summer temperature was 19. 6 °C, that is 3,4 K higher than the mean value. At August 9 and August 13, 2006, the highest maximum temperatures ever registered in Germany, 40. 2 °C, have been measured in Karlsruhe and in Freiburg. This extreme weather was caused by a blocking action of the westerly circulation due to a stationary wave forming a so-called Omega-weather type. High pressure systems with cloudless sky conditions permitted extreme sun radiation and caused repeatedly record temperatures. In southern Germany 53 hot days with maximum temperatures higher than 30 °C have been registered. This heat wave concerned not only Germany, but large regions of Western Europe with France and Great Britain. Other European countries like Switzerland, Spain, Portugal and Italy have been concerned, too.

The questions are (1), if this extreme event is in relation with the human impact on the climate system via the emission of greenhouse gases and (2), if such events will be more frequent in the future

Based on a climate change simulation the distribution of the maximum temperatures of the summer 2003 indicate that this extreme summer is expected to be a normal one by the end of this century in Central Europe (Beniston 2004, Schär et al. 2004, Meehl & Tebaldi 2004; Fig. 1)!

This is in good accordance with the IPCC (2001) statements that in the future extreme weather events are very likely and that more hot days over nearly all land areas are very likely, too.

2 Thermal Climate in Cities: The Urban Heat Island

The most important "local climate change" due to human building activities is the so-called urban heat island (UHI). Since about half a century many investigations have shown the importance of this phenomenon which is caused by the storage of short wave solar energy in the buildings during the day and its liberation by long wave radiation in the evening and night. The larger the city and the

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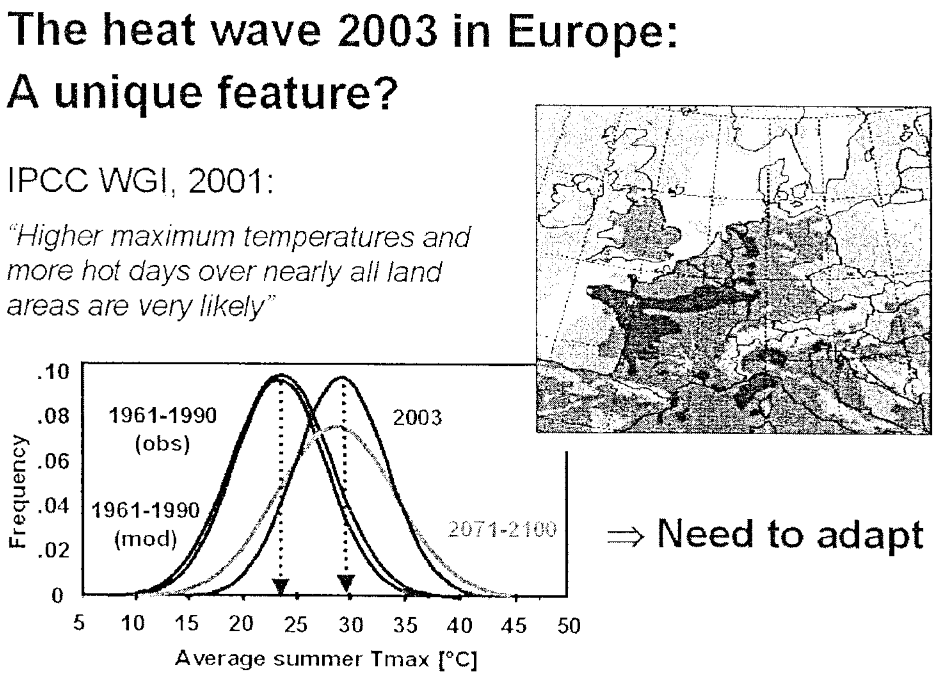

Fig. 1 The heat wave 2003 in Europe: Actually a unique feature, but a normal event in 2071–2100

denser its build-up structure the more intense is the city's heat island or heat archipelago. Maximum differences of about 10 K and more between city centers and rural areas ($\Delta(\max)T_{urban} - T_{rural}$) have already been registered in large agglomerations. Fig. 2 gives an example of the relation between the size of a city and its maximum heat island.

For sure the UHI is largest in the radiation rich seasons – e.g. the European summer months – or tropical and subtropical climates (e.g. summer dry subtropics of the Mediterranean coasts). Until this point there was only the question of global and local air temperature change. The climatic environment, however, includes much more elements which have to be taken into account, if we like to bring together climatic conditions and human health.

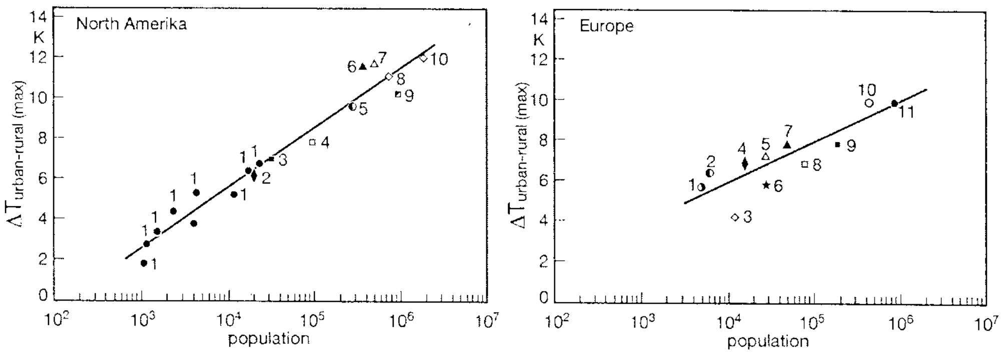

Fig. 2 European and North American Maximum Urban Heat Islands: relation between $\Delta(\max)T_{urban} - T_{rural}$ and log population (Oke 1973): a) North America – 1 Nine Quebec settlements, 2 Corvallis, 3 Palo Alto, 4 San Jose, 5 Hamilton, 6 Edmonton, 7 Winnipeg, 8 San Francisco, 9 Vancouver, 10 Montreal; b) Europe – 1 Lund, 2 Uppsala, 3 Reading, 4 Karlsruhe, 5 Utrecht, 6 Malmö, 7 Sheffield, 8 Munich, 9 Vienna, 10 Berlin, 11 London (data from literature published between 1929 and 1972)

3 The Thermal Environment

One of the fundamental issues in human biometeoriogy is the assessment and forecast of the thermal environment. This is due to the need for human beings to balance their heat budget to a state very close to his/her thermal environment in order to optimise his/her comfort, performance and health. This means to keep heat production and heat loss in a equilibrium in order to keep the body core temperature at a constant level. Heat is produced as a result of the metabolic activity required to perform activities. The body can exchange heat by convection (sensible heat flux), conduction (contact with solids), evaporation (latent heat flux), radiation (long- and short-wave), and respiration (latent and sensible).

The heat exchange between the human body and the thermal environment (Fig. 3) can be described in the form of the energy balance equation which is nothing but the application of the first fundamental law of thermodynamics:

$$M + W + Q^* (Tmrt,v) + QH (Ta,v) + QL (e,v) + QSW (e,v) + QRe (Ta,e) + S = 0 \qquad (1)$$

M	Metabolic rate (activity)
W	Mechanical power (kind of activity)
Q^*	Radiation budget (short wave and long wave radiation fluxes)
QH	Turbulent flux of sensible heat (convection)
QL	Turbulent flux of latent heat (diffusion water vapour)
QSW	Turbulent flux of latent heat (sweat evaporation)
QRe	Respiratory heat flux (sensible and latent)
S	Storage

The meteorological input variables include air temperature Ta, water vapour pressure e, wind velocity v, mean radiant temperature Tmrt including short- and long-wave radiation fluxes, in

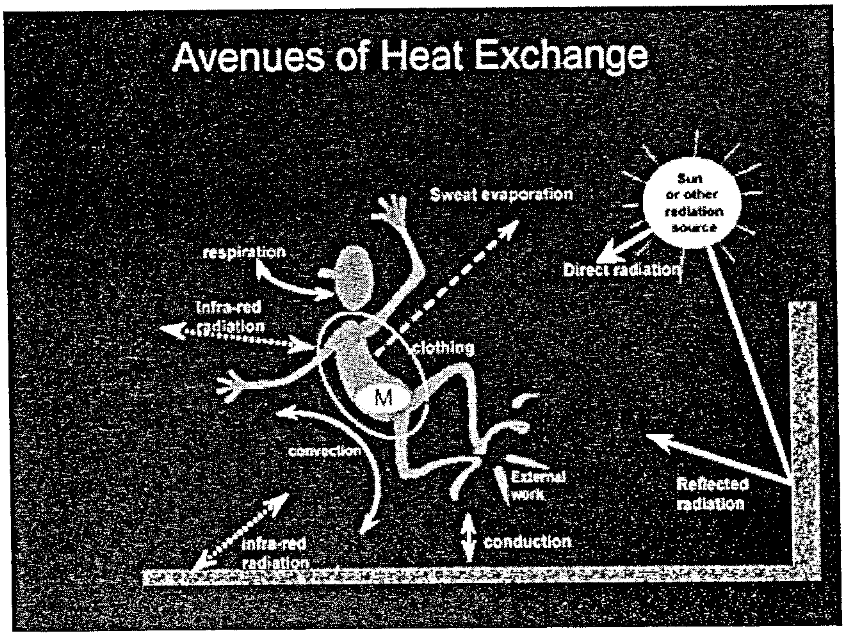

Fig. 3 The human heat budget (Havenith, 2003, in Koppe et al. 2004)

addition to metabolic rate and clothing insulation. In eq.1 the appropriate meteorological variables are attached to the relevant fluxes.

It is important to take into account all these variables for the complete description of the thermal conditions, thermal comfort or discomfort.

Thus, consequently dealing with the thermo-physiologically significant assessment of the thermal environment requires the application of a complete heat budget model that takes all mechanisms of heat exchange into account as described in eq. 1. Such models possess the essential attributes to be utilised operationally in most biometeorological applications in all climates, regions, seasons, and scales. Fanger's (1970) PMV-(Predicted Mean Vote) equation can e.g. be considered among the advanced heat budget models. This approach is the basis for the operational thermal assessment procedure Klima-Michel-model (Jendritzky et al., 1979; Jendritzky et al., 1990) of the German national weather service DWD with the output parameter "perceived temperature, PT" (Staiger et al., 1997) that considers a certain degree of adaptation by various clothing.

4 Thermo-Physiological Modeling and Urbanization

The importance of the described thermo-physiologic approach is evident. Simple indices taking into account only temperature and humidity are not any longer sufficient. An example from an urban street canyon shows it clearly (Fig. 4): Radiation received at the human body is totally different at the sunny and shadowed site of the street and so are the surface temperatures of the asphalt and the walls. Wind speed is highest in the middle of the street. Air temperature, however, is nearly the same at both sides of the street canyon. Only the modeled Perceived Temperature represent the thermal environment in a correct way (as we perceive when we cross the street from the sun to the shadow).

In Berlin, the heat load in August 2003 has been modeled comparing 3 different neighbourhoods (Fig. 5): The open esplanade Alexanderplatz in the eastern city center with only a few trees, few shaded areas and a large sky view factor (a), the densely built-up Potsdamer Platz, in the city center as well, but with a smaller sky view factor and larger shaded surfaces (b), and the garden suburb

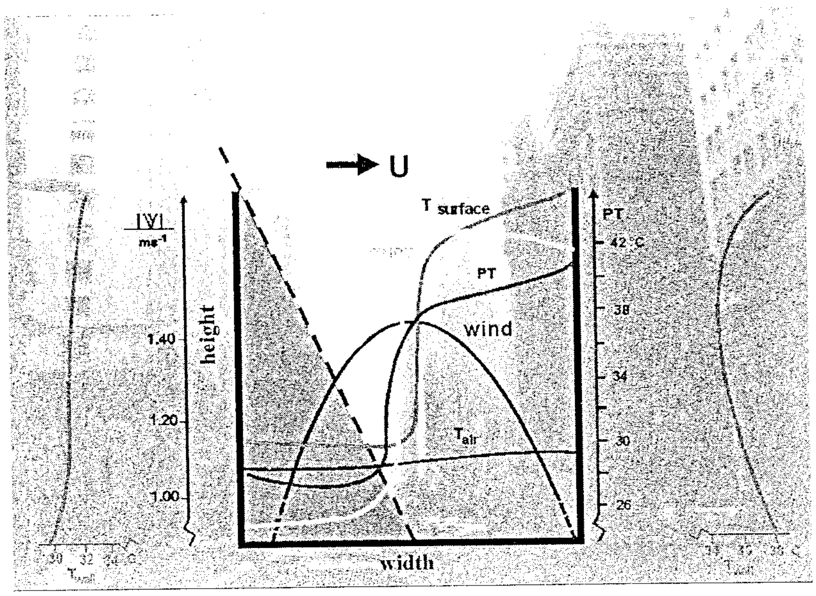

Fig. 4 Meteorological and biometeorological conditions in a cross section of a street

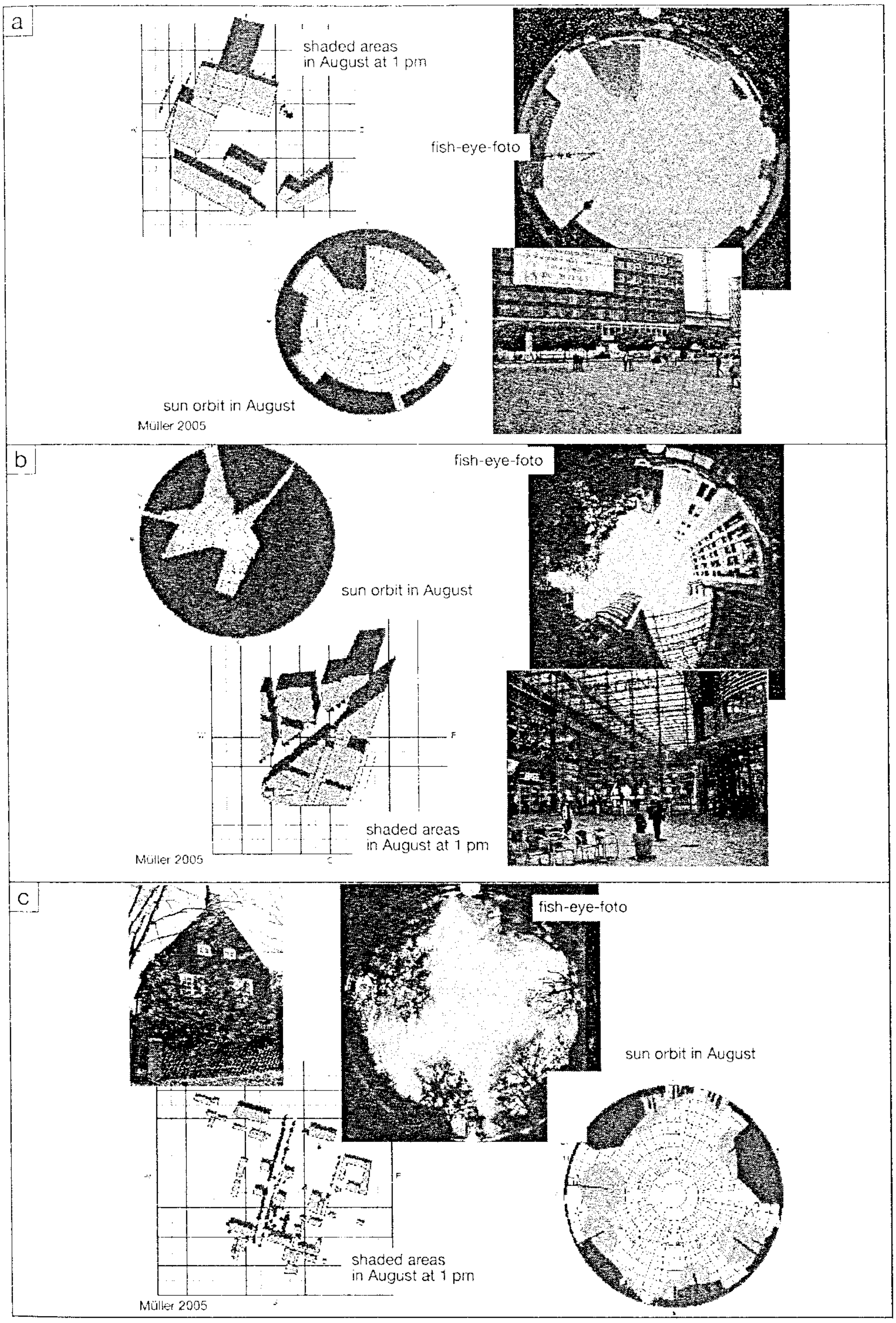

Fig. 5 Heat load in different neighbourhoods of Berlin, August 2003: a) City center – Alexanderplatz, b) City center – Potsdamer Platz, c) Garden suburb Dahlem, d) frequency of different heat load in comparison of the 3 neighbourhoods

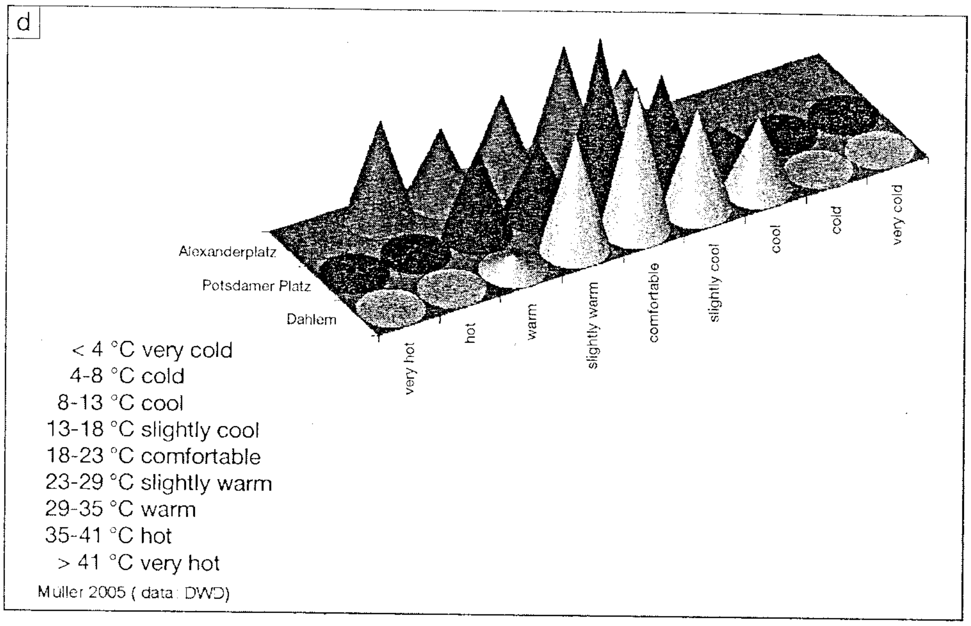

Fig. 5 (continued)

Dahlem with a reduced sky view factor due to numerous trees (c). The model results (d) show, that the Alexanderplatz was the neighbourhood with the highest heat load, followed by the Potsdamer Platz and Dahlem. Between August 1 – 15, 2003, 12 days with a moderate to high heat load have been registered at the Alexanderplatz. The Potsdamer Platz showed a lower heat load, because of its reduced sky view factor, but a higher one than Dahlem. So, densely built-up neighbourhoods show high heat loads, even if the direct radiation is reduced, due to the heat storage in walls and sealed surfaces which are missing nearly completely in the garden suburb.

5 Heat Waves and Human Health: the Future has Already Started

There are numerous epidemiological studies published which impressively show worldwide the health impact of extreme thermal conditions such as heat waves. During the hot summer 2003 in Europe, in particular in August, between 35.000 and 55.000 heat related extra deaths occurred. It can be assumed that the urban heat island effect (UHI) has intensified the regional heat load. If the calculations are correct – and there are no doubts about, that heat waves like the European one in 2003 will be in the future more frequent and perhaps even more intense, then we have to develop different ways of coping with this heat vulnerability. An impressive example of the already now enhanced mortality during heat waves in Southern Germany is given in fig. 6. The figure shows the deviation of the total mortality rate during the days before and after the average of nine extreme heat waves (1968-1997). The mortality curve follows closely the modelled "Perceived Temperature" (Jendritzky et al. www.utci.de/documents/Perceived_Temperature).

5.1 The Universal Thermal Climate Index UTCI

The International Society on Biometeorology ISB recognised the issue presented above some years ago and established a Commission "On the development of a Universal Thermal Climate Index

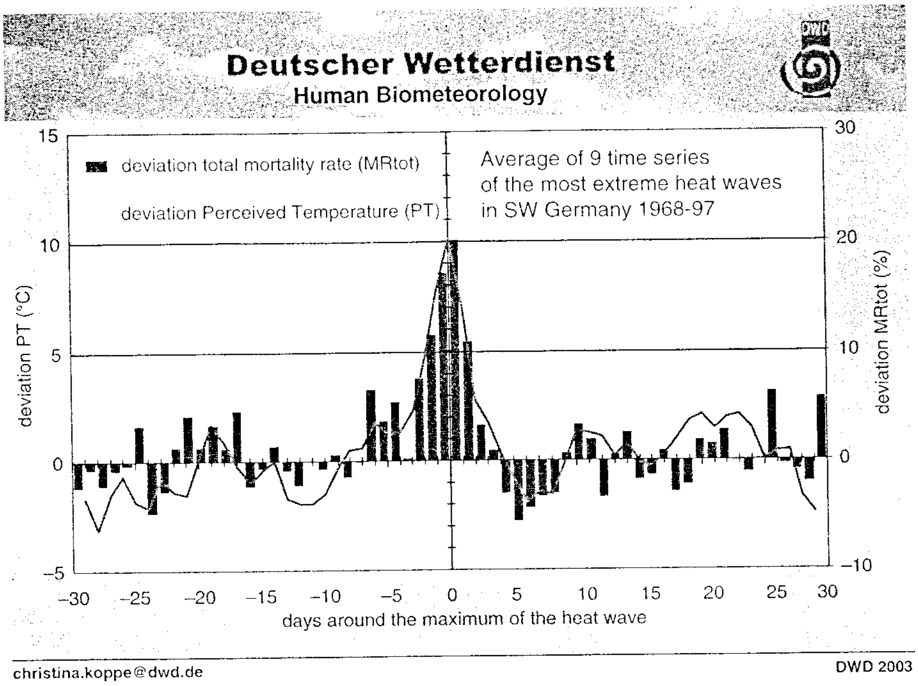

Fig. 6 Deviation of the total mortality rate during the days around the maximum of a heat wave; average of nine time series of the most extreme heat waves in Southwest Germany (1968-1997); the curve of the modeled "Perceived Temperature" follows closely the mortality deviation (Koppe et al. 2004)

UTCI" (Jendritzky et al., 2002; http://www.utci.de). Since 2005 the COST Action 730 (Cooperation in Science and Technical Development) of the European Science Foundation ESF provides the basis that scientists can join together on a regular basis in order to achieve significant progress in deriving such an index. Aim is an international standard based on scientific progress in human response related thermo-physiological modelling of the last 30 years (Fiala et al., 2001; Kusch et al. 2004) including the acclimatisation issue. This work will finally be made available in a WMO "Guideline on the Thermal Environment" so that every national health service can then easily apply the state-of-the-art procedure for its specific purposes. The guideline will provide numerous examples for applications and solutions for handling meteorological input data.

5.2 *The Need for Adaption*

The need for adaptation to the growing problems of the thermal environment is evident. In addition demographic factors like the growing number of senior citizens have to taken into account, because elderly people have more difficulties to deal with thermal stress. Therefore the development of suitable measures for adaption is necessary. Two levels have to be distinguished in order to reduce the urban thermal stress indoors and outdoors:
Long-term and short term adaption to future enhanced heat stress.

5.2.1 Long-Term Adaption

Long-term measures need a longer implementation time and apply especially to *urban planning* and *building design.*

Outdoors:

- Creation of green and open spaces, especially with trees
- Ventilation and air flow
- Enhancement of albedo (less heat storage by absorption of short wave radiation)
- Reduction of anthropogenic heat production

Indoors:

- Thermal capacity of buildings
- Position of apartments
- Control of solar irradiation
- Passive cooling

5.2.2 Short-Term Adaption and Heat Health Warning Systems

Short-term adaption measures are possible to realize in a short run and apply especially to the set-up of *Heat Health Warning Systems (HHWS)* which take into account the actual weather and the forecast of the next few days. Lives would have been saved if adequate Heat Health Warning Systems would have been in action, as promoted by the WMO/WHO/UNEP showcase projects in Rome and Shanghai. Such systems are based on biometeorological forecasts expecting exceeding of an agreed threshold (heat load forecast). The following interventions (a locally adjusted emergency response plan) belong then to the responsibility of the public health service. HHWSs must be prepared in advance with complete descriptions of all processes (Kovats & Jendritzky 2006). In addition self-organizing networks will allow to take into account as well outdoor as indoor conditions.

Sensor systems (e.g. HHWS) require a communication infrastructure capable of transporting captured sensor data (temperature, humidity, air pollution, etc.) to a central data collection and processing center. This communication infrastructure must be low-cost, real-time, dense, and quickly adaptable. No existing technology satisfies/optimizes all requirements at the same time. Hence, solutions are needed that are tailored to specific usage scenarios.

The Berlin RoofNet project [www.berlinroofnet.de] has demonstrated that it is possible to build an autonomous wireless information network in the city of Berlin, at a moderate budget. Main points in its design are: The network evolves spontaneously (ad-hoc), without explicit prior planning. It does not require a central administrative authority, like an operator. Nodes (access points) communicate with each other and with client stations (laptops, sensor stations). The network is self-organizing: nodes create network structures automatically and determine configuration parameters without human intervention. Inexpensive Commercial Off The Shelf (COTS) hardware is used, such as IEEE 802.11 g WLAN, that operates in the unlicensed 2.4 GHz ISM band. Communication is close to real-time (delay ~ 0.5-1 seconds), robust (mesh-structure with redundant paths) and based on the Internet Protocol, which allows for easy integration with existing applications and with the public Internet (where available).

The option of reducing cost even further and simultaneously increasing the coverage area by a large factor is available, at the cost of significantly increased delay times. An experimental technology called DTN (Delay Tolerant Networks) uses mobile objects (busses, cars, even people) as carriers of information: Sensors capture data and aggregate them locally - using small-scale wireless networks. Selected busses are equipped with access stations that, if they enter the communication range of the sensor station/network, retrieve all data within seconds, store it, carry it, and finally deliver it to a central data collection station. Dependent on bus frequency and reliability of bus schedules, delay times range between few hours and 1 day. In addition to carrying sensor data, the DTN infrastructure could also carry messages of people living in the covered areas (similar to E-mail). This additional use of the proposed communication infrastructure may not be attractive to people with always-online broadband Internet access, but for poor people it may be the only means for tele-communication available to them.

For a later integration with already existing applications of the National Meteorological Services it is of strategic importance that the communication infrastructure is IP-based. An evaluation of the behaviour of the network infrastructures is almost impossible without accompanying model investigations. By experimental adjustment of the net topology and the protocol software iterative improvements in the behaviour and thus positive effects on the quality of the planned communication infrastructure can be gained. The expenditure, which has be to be paid repeatedly for each concrete configuration and installation of a monitoring system, should be strongly reduced by simulations of the time behaviour of such systems with consideration of the dynamic load and the changing environmental influences to each communication computer of the monitoring system.

In order to be able to realize this complex task, a library of parameterisable model components should be developed, which enables the efficient configuration of the monitoring system models with appropriate experimentation and evaluation support. An established approach for that is an adoption of the OdemX library (Fischer & Ahrens 1996; Gerstenberger 2003), developed in C++ for the modelling and simulation of time-discrete and time-continuous processes.

6 Conclusion

The superposition of five factors: Heat waves, thermal stress, rapid urbanization, growing number of elderly people and global climate change exclude simple solutions. Nevertheless adaptation measures are possible (Kirch et al. 2006). Intelligent short-adaption measures like Heat Health Warning Systems can be installed already nowadays. Long-adaption measures need more time to be developed and introduced; however, global climate change and rapid urbanization, especially the growing number of megacities, will complicate this issue in the future even more.

References

Beniston, M., 2004: The 2003 heat wave in Europe: A shape of things to come? An analysis based on Swiss climatological data and model simulations. Geophys. Res. Letters 31, L02202, 1–4.

Berlin Roof Net project at Humboldt University Berlin. http://www.berlinroofnet.de.

Fanger, P.O., 1970: Thermal Comfort. Analysis and Application in Environment Engineering. Danish Technical Press, Copenhagen.

Fiala D., Lomas K.J. and Stohrer M., 2001: Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. Int. J. Biometeorol., 45, 143–159.

Fischer, J.; Ahrens, K. (1996): Objektorientierte Prozeÿsimulation in C++. Addison-Wesley Publishing Company 1996.

Gerstenberger, R. (2003): ODEMx: Neue Lösungen für die Realisierung von C++- Bibliotheken zur Prozesssimulation. Diplomarbeit Institut für Informatik, Humboldt-Universität zu Berlin.

Jendritzky, G., Sönning, W., Swantes, H.J., 1979: Ein objektives Bewertungsverfahren zur Beschreibung des thermischen Milieus in der Stadt- und Landschaftsplanung ("Klima-Michel-Modell"). Beiträge d. Akad. f. Raumforschung und Landesplanung, 28, Hannover.

Jendritzky, G., G. Menz, W. Schmidt-Kessen & H. Schirmer (1990): Methodik zur räumlichen Bewertung der thermischen Komponente im Bioklima des Menschen (Fortgeschriebenes Klima-Michel-Modell). Akademie für Raumforschung und Landesplanung, Beiträge 114, Hannover.

Jendritzky, G., Maarouf, A., Fiala, D., Staiger, H., 2002: An Update on the Development of a Universal Thermal Climate Index. 15th Conf. Biomet. Aerobiol. and 16th ICB02, 27 Oct – 1 Nov 2002, Kansas City, AMS: 129–133.

Kalkstein, L.S. & K.E. Smoyer (1993): Human biometeorology – the impact of climate change on human health – some international implications. Experientia 49 (11): 969–979

Kalkstein, L.S., Jamason, P.F., Greene, J.S., Libby, J. & Robinson, L. (1996): The Philadelphia Hot Weather – Health Watch / Warning System: Development and Application, Summer 1995. – American Met. Soc. 77 (7): 1519–1528.

Kalkstein, L.S. & J.S. Greene (1997): An evaluation of climate/mortality relationships in large US cities and the possible impacts of climate change. Environmental Health Perspectives 105 (1): 84–93

Kirch, W., Menne, B., Bertollini, R., 2006: Extreme Weather Events and Public Health Responses. Springer, Berlin, 303 pp.

Koppe, C., S. Kovats, G. Jendritzky & B. Menne (2004): Heat-waves: risks and responses. World health Organization. Health and Global Environmental Change, Series, No. 2. Copenhagen.

Kovats, S. & G. Jendritzky (2006): Heat-waves and Human Health. In: Menne, B. & K.L. Ebi (eds.): Climate Change and Adaptation Strategies for Human Health. Darmstadt: 63–97

Kusch, W., Hwang Yung Fong, Jendritzky, G. & Jacobsen, I. (2004): Guidelines on Biometeorology and Air Quality Forecasts. WMO/TD No. 1184, Geneva.

Meehl, G.A. & Tebaldi, C. (2004): More Intense, More Frequent, and Longer Lasting Heat Waves in the 21st Century. – Science 305: 994–997.

Müller, M. (2005): Humanbioklimatologische Untersuchungen im Vergleich Berlin und Umland. Diplomarbeit Geographisches Institut, Humboldt-Universität zu Berlin.

Oke, T.R. (1973): City size and the urban heat island. In: Atmospheric Environment 7: 769–779.

Pentland, A.; Fletcher, R.; Hasson, A. (2004): DakNet - rethinking connectivity in developing nations. Computer, Vol. 37, No. 1: 78–83.

Schär, Ch., Vidale, P.L., Lüthi, D., Frei, Ch., Häberli, Ch., Liniger, M.A. & Appenzeller, Ch. (2004): The role of increasing temperature in European summer heatwaves. – Nature 427: 332–336

Staiger, H., Bucher, K., Jendritzky, G., 1997: Gefühlte Temperatur. Die physiologisch gerechte Bewertung von Wärmebelastung und Kältestress beim Aufenthalt im Freien in der Maÿzahl Grad Celsius. Annalen der Meteorologie, Deutscher Wetterdienst, Offenbach, 33: 100–107.

Weischet, W. & Endlicher, W. (2000): Regionale Klimatologie, Teil 2. Die Alte Welt. Europa, Afrika, Asien. Stuttgart, Leipzig, 626 pp.