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Human Bioclimatological Questions and Solutions in Applied Urban Climatology

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Abstract: Epidemiological studies show the importance of the atmospheric environment, esp. of heat load on health and well-being, e. g. taking mortality rates as parameter. A thermophysiologically significant assessment succeeds by using a complete heat budget model of the human being, as e. g. the Klima-Michel-model. For a bioclimatological assessment of urban structures influencing the heat exchange conditions at the near-ground living space (the canopy layer) in a scale of 1:10.000 the urban bioclimate model UBIKLIM has been developed as an expert system, using GIS-techniques. On the basis of the planning parameters UBIKLIM provides valuable information for planning decisions.

Key words: Epidemiology, Urban bioclimatology, Human heat budget, Heat load

1. URBAN CLIMATE AND HUMAN HEALTH

Health is the state and behaviour of the organism as a whole in balance to the interactions with the natural and social environment. WHO defines health as state of complete physical, mental and social well-being, not merely as the absence of disease and infirmity.

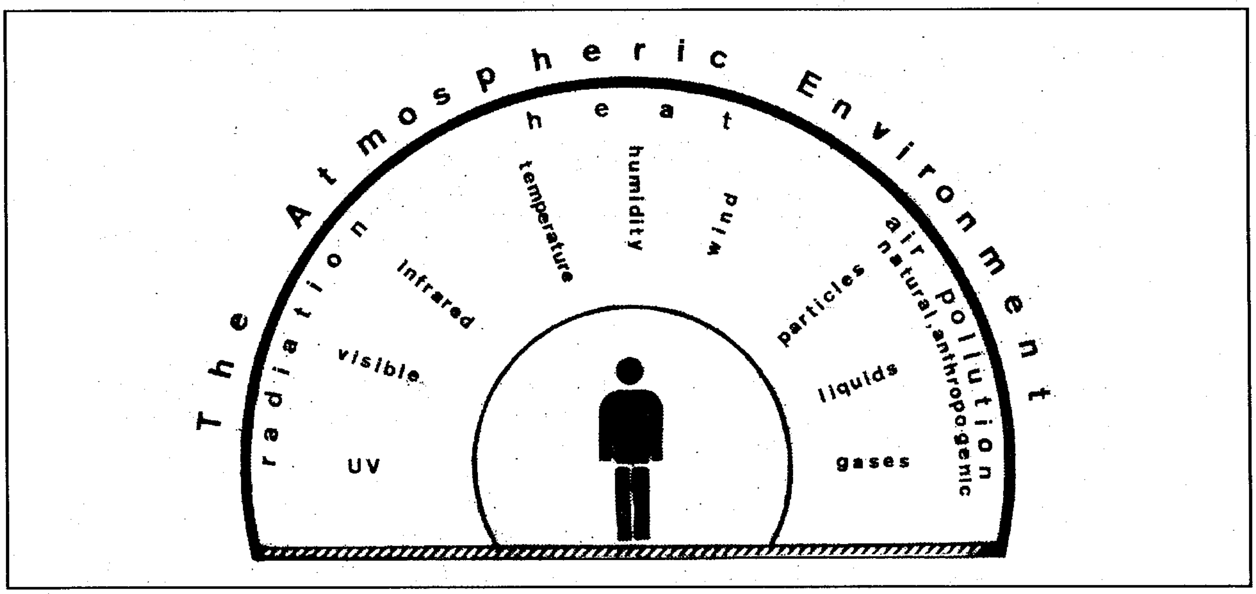


Fig. 1 The Atmospheric Environment

The physical and chemical properties of the atmosphere (Fig. 1) as elements of both weather and climate, are part of our environment (Jendritzky, 1992). In order to maintain health, well-being, and performance the human organism is in a permanent state of confrontation with this environment. Adaptive reactions of the organism therefore can be taken as a response to disturbances by the atmosphere. A healthy organism will accomplish adaptation by means of the autonomic regulation, which mostly goes unnoticed. The adaptability of sensitive, elderly, and sick persons, pregnant women, and children is, however, more liable to be overtaxed. Particularly cardiovascular diseases and diseases of the respiratory tract may be triggered or aggravated, depending on the individual predisposition.

The multitude of affect variables shows that usually no simple cause-effect relations can be expected between the atmospheric environment and human health. Consequently, the biological response to the different affecting parameters may range from no effect, i.e. complete health, to inconvenience, impairment, subclinical alterations and even clinically manifest damage and an increased mortality rate. But in general environmental influences tend to be weak, at least in developed countries (Wichmann et al., 1992). Consequently it is often difficult to establish critical values and standards.

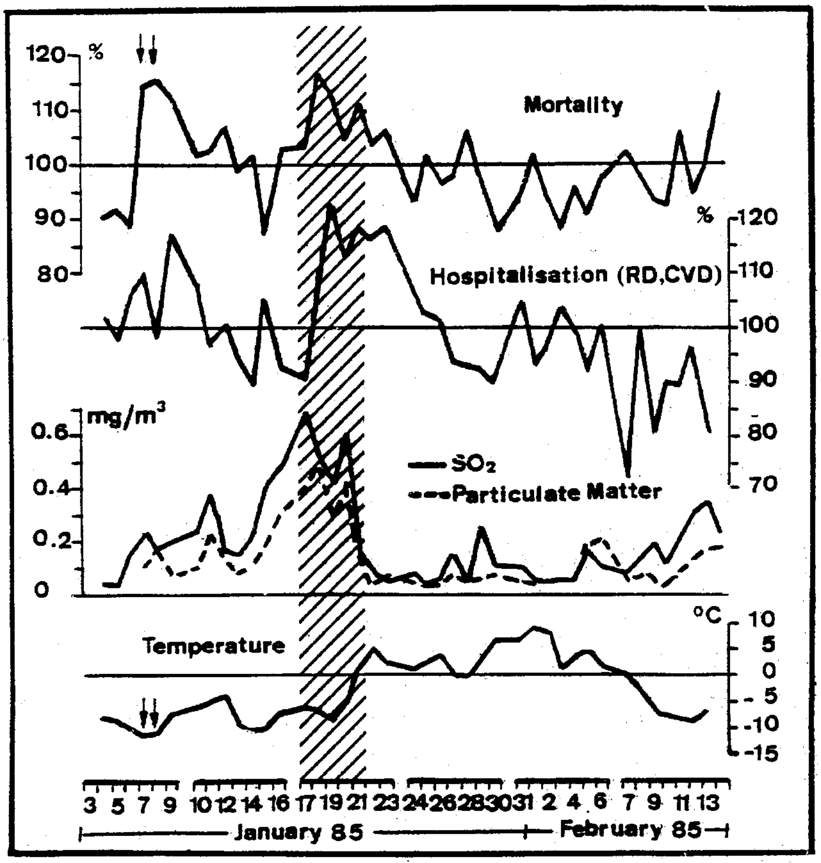


Fig. 2 Smog event Ruhr area 1985. Daily mortality rate and hospitalization (for respiratory, RD, and cardiovascular, CVD, diseases). SO_2, particulate matter, air temperature 24 h means. Arrows: extremely cold days; hatched area: smog event (Wichmann et al., 1987)

Epidemiological studies show the effects of extreme conditions (heat load, cold stress, air pollution) on morbidity and mortality (Jendritzky, 1992). A good example of an air pollution effect is the smog event in the Ruhr area in Germany in 1985 (Fig. 2) (Wichmann et al., 1987). The parameters mortality rate and hospitalization due to respiratory and cardiovascular diseases follow the increase of air pollution with a short time-lag. But the highest value in daily mortality occurs ten days before, associated with a very low air temperature of -15°C; an indication that the atmospheric conditions of heat exchange must play an important role for health, well-being, and physical performance of a human being.

The significance of the meteorological conditions as confounder or modifier of the effects of air pollution depends on the season. In winter the influence of e.g. temperature changes are lower than in summer. Basically weather/climate as well as air pollution may be major elements in explaining the variance in the mortality data (Wagner, 1995). Fig. 3 shows that during "offensive air masses", whoes stressing properties on the human organism are well known, the highest mortality rates occur while the influence of air pollution is low or even zero. It is true that during all other meteorological conditions mortality increases with increasing air pollution but remains below the total mean value; hence the "add-on effect" is small (Kalkstein et al., in press).

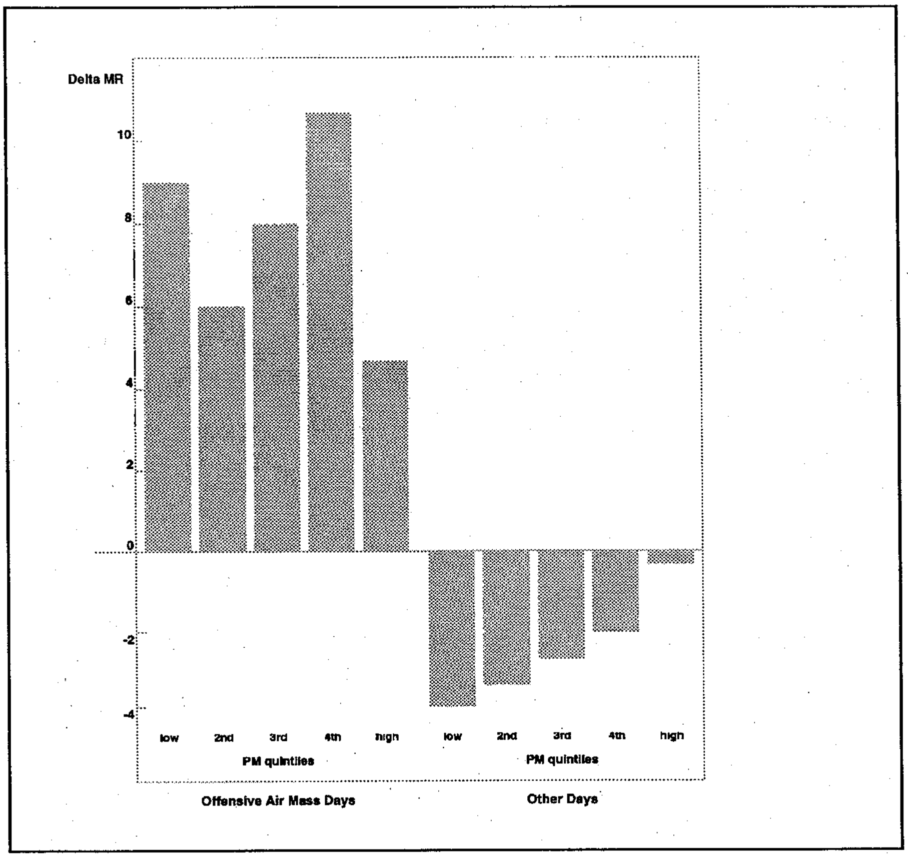


Fig. 3 Mean daily mortality (variation from baseline) for PM quintiles, Philadelphia, PA (Kalkstein, in press)

Some mortality/climate studies show that sometimes the relation is weak in a wide range of moderate temperatures. Not until after exceeding a threshold which depends on the climate, the mortality increases drastically. The data of Shanghai show such a behaviour (Fig. 4) (Kalkstein and Smoyer, 1993, Kalkstein, 1994; McMichael et al., 1996).

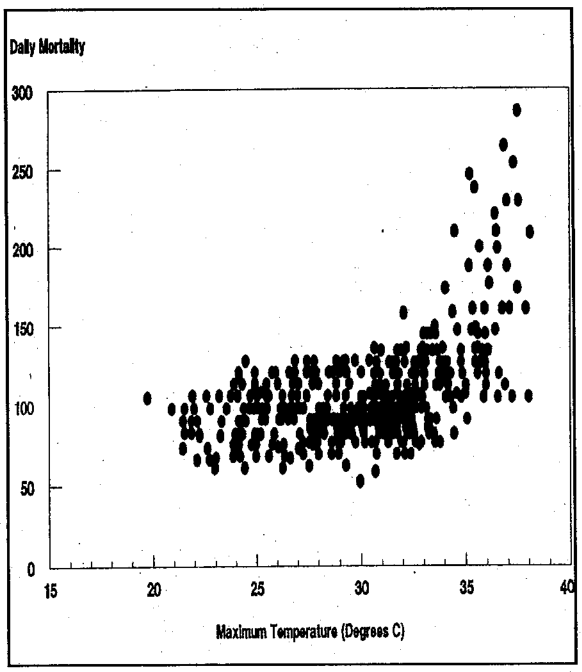
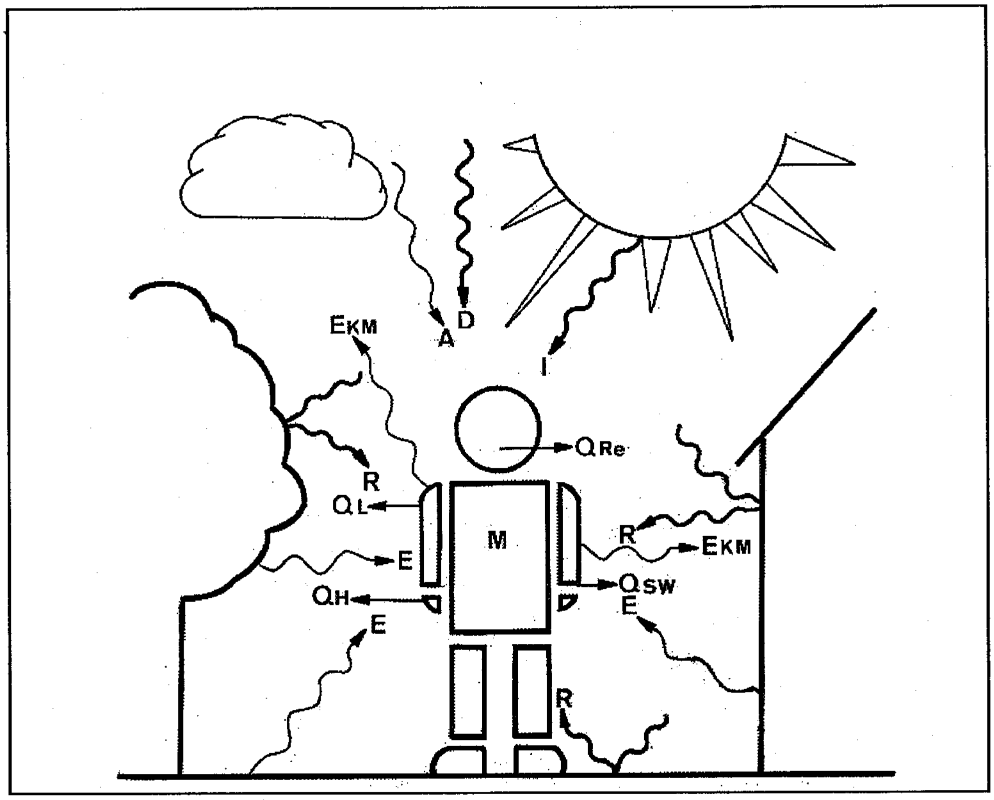


Fig. 4 Relationship between mortality and air temperature in Shanghai in summer

In spite of these results the relevance of air pollution for human health is generally accepted by society, population and authorities, sometimes it is even overestimated. A great number of standards exist for assessments, which urban planning can take into account, without permanently being forced to give the reasons for health effects. For the thermal conditions, which will be treated in the following, the standard is defined in the VDI-guideline: "Human Bioclimatological Assessment of Climate and Air Pollution for Regional and Urban Planning". According to it the discomfort equation of Fanger (1972) is taken as state-of-the-art for human bioclimatological analyses and assessments of the meteorological conditions of heat exchange. This equation which in addition to a radiation model is the major module in the Klima-Michel-Model (Fig. 5), connects heat production of the human body as function of activity with the meteorological conditions of heat exchange which depend on air temperature, humidity, wind velocity and radiant fluxes, considering insulation of clothing (Jendritzky, et al., 1990; Höppe, 1984). Thus the Klima-Michel-model is suitable to provide physiologically significant information for planning purposes on the basis of climate data (Jendritzky and Nübler, 1981; Jendritzky, 1983, Jendritzky and Sievers, 1989).



M	metabolic rate	radiation budget Q*	
Q_H	turbulent flux of sensible heat	I	direct solar radiation
Q_{SW}	turbulent flux of latent heat (perspiration)	D	diffuse solar radiation
Q_L	flux of latent heat by water vapour diffusion	A	atmospheric counter radiation
Q_{Re}	heat flux of respiration (sensible and latent)	E	emission of the surroundings
		E_{KM}	infrared radiation from men`s surface

Fig. 5 The Thermal Environment

The application of this complete heat budget model of the human being to daily mortality data from 25 years in SW-Germany (2,5 Mill. cases) demonstrates, that cold stress as well as heat load obviously are stressors (Fig. 6) (Jendritzky et al., 1997). The heat exchange conditions are described in terms of a so-called perceived temperature PT which relates them to a standardized outdoor environment (shade, calm, highest possible degree of adaption by clothing, walking 4 km/h) (Staiger et al., 1997). Persons from risk groups with limited adaptation capacity are not able to resist such stress factors. These results conform well to findings in other climates! Particularly the increase in mortality of more than 10% during heat load conditions over 10% is relevant to urban planning, i.e. a reduction of the urban heat island must be a target. This is impressively confirmed by the mean relation of daily mortality (Fig. 7) to heat waves even in a moderate climate.

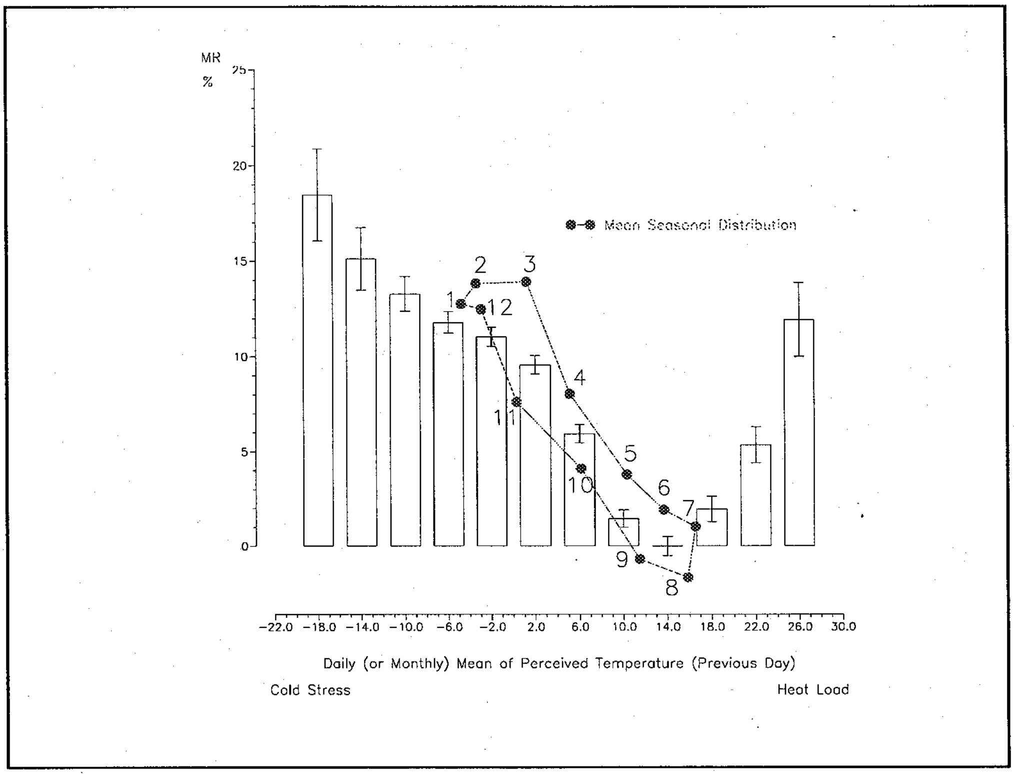


Fig. 6 Relative deviation of mean daily (or monthly) total mortality rate MR in % from mean value during thermal neutrality in the observed perceived temperature range in SW-Germany 1968-93. Bars indicate the 5% confidence interval.

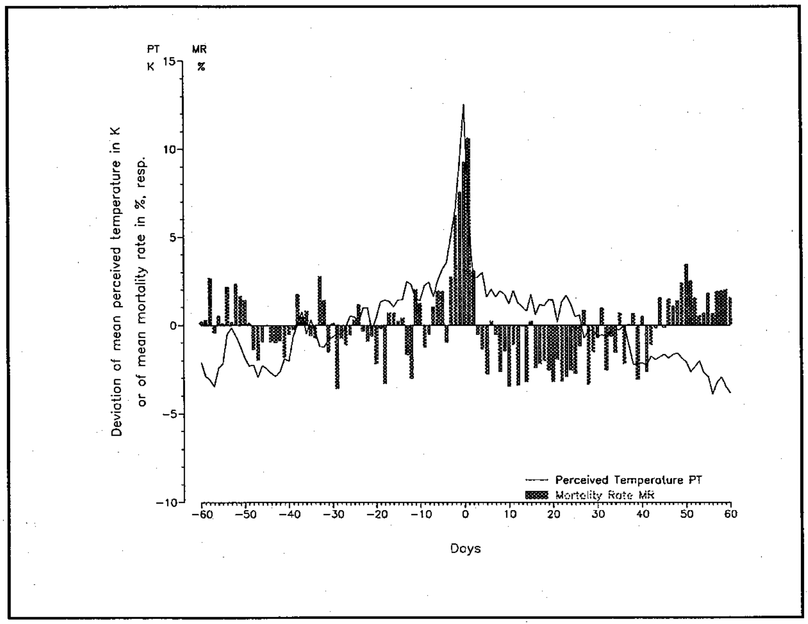


Fig. 7 Averaged time series of heat load events 1968 - 1993 in SW-Germany (base: highest perceived temperature PT of each year) and mortality rates MR

2. CAN URBAN PLANNERS CONTROL URBAN CLIMATE AND BY THIS THE ATMOSPHERIC ENVIRONMENT OF HUMAN BEINGS ?

In Germany, and probably in some other industrialized countries, development planning must by law contribute to safeguarding and improving of climate and air as part of the natural elements of life. The target is creating and safeguarding healthy conditions for life and work. In this context urban climate is an impressive example of a man-made climate change. For that account urban climate is obviously susceptible, and therefore has to be considered in good time (Bitan, 1992; Baumüller et al., 1993; Givoni, 1989; Jendritzky, 1988; Landsberg, 1981; Mayer, 1993, 1996; Moriyama et al., 1995).

With respect to health, well-being, and performance the following questions are of interest to urban planners (Grätz et al.; 1994, Jendritzky, 1995):

- Which urban settlement structures tend to be bioclimatologically stressful ?
- How can development plans be optimized with respect to human health ?
- Which arguments for development regulations can be derived ?
- Which areas are appropriate for a new development ?
- Where is an urgent need for action ?

Climate is an abstract term; the statistics of atmospheric fields and processes do not yet provide automatically information relevant for planning purposes. Thus for a climate related preventive planning a bioclimatological view of climate information is necessary. Is heat island positive or negative ? For which question ? Planners need an assessment!

In a given climate the micro-scale thermal environment of the human being is determined by the land use and its interactions (Bründl et al., 1986; Miyazaki et al., 1995; Oke, 1981, 1982, 1984; Weischet et al., 1977; Yoshida et al., 1995), i.e. by the planning variables in Tab. 1:

Forest
Water
Parks
Wider streets
Fields
Unpaved urban areas
Sport courts
Railway lines
Industrial sites*
Commercial sites*
Areas with public institutions*
Residential areas*

* Additionally required:
Building density (number of buildings per area unit)
Building height
Degree of pavement
Greenery interdispersion

Tab. 1 Land use types required for UBIKLIM

So a bioclimatological assessment of the effect of these planning parameters is necessary. Such data (if possible in 10 m resolution) are required for the <u>u</u>rban <u>bio</u><u>cli</u>mate <u>m</u>odel UBIKLIM (Grätz et al., 1992; Grätz et al., 1994), originally derived on the basis of MUKLIMO-1 (Sievers and Zdunkowski, 1986; Jendritzky and Sievers, 1987, 1989). With the aid of UBIKLIM based on digital land use data and appropriate terrain data, the spatial distribution of heat load intensities is computed on a scale (usually 1:10.000 or 1:25.000) relevant for the desired planning purpose in an urban environment. The analysis and assessment of micro-scale land use data with the aid of UBIKLIM immediately show the problematic areas, in which e.g. an improvement of the climatic conditions is indicated.

A great advantage of a numerical model like this expert system is the possibility to study different planning variants and ideas or the sensitivity of the bioclimate on changes in the parameters which describe the settlement structure, because only the planning variables have to be changed for the computation (Grätz et al., 1994). Thus the best possible bioclimate under the meso-climatic and other preconditions can be approached and the according regulations for building up the area established by the authorities. Greenery interdispersion, greenery on roofs and facades, degree of pavement, building density etc. should be regulated in the development plan. The described model provides arguments for planners, architects, decision makers, and authorities.

3. Applications of UBIKLIM

In the following two examples of applications of UBIKLIM are briefly described in order to show the value of the approach:

Karlsruhe (SW-Germany; ca. 270.000 inhabitants)

The first objective was to analyse the current bioclimatological situation, and secondly to determine the impact on the bioclimate caused by planned changes of land use, especialy of the urban structure.

As input data UBIKLIM usually requires a digital height model (DHM) with a 10m resolution and appropriate land use data, as described before. For the bioclimatological study of the Karlsruhe area a DHM with the 10m resolution could be derived from an already existing DHM with a 50m resolution. In order to obtain the land use information the investigation area was devided into 4756 districts, each one of them characterized by its own land use type or - if it was a matter of a built-up area - additionally by its typical development parameters. Thereby 2393 undeveloped districts and 2363 built-up areas have been analysed. The map of the land use, as applied in the model, is shown in figure 8, for more clearness in a simplyfied form.

After the application of these data sets to UBIKLIM a bioclimate map of the current situation (fig. 9) is resulting. It shows the spatial distribution of the number of days with heat load as an annual mean. The result is made up by background heat load and the additional load caused by the given conditions of the urban development planning.

Whereas the largest part of the Karlsruhe area is situated in the almost flat Rhine valley, the multiform ways of the land use and the interactions between adjacent districts are mainly responsible for the differences in the bioclimate within this area. Only in the south-east of the city orography obviously also has a modifying influence which has to be attributed to the rising slopes of the Black Forest.

The current bioclimatological situation is remarkably formed by the three prevailing land use types: forest, open space (for example meadows) and development. Forest and open space are dominant in the outer districts and the rather favourable conditions have to be ascribed to their compensatory effects. Contrary to this an extensive area of strong heat load has established in the city center. Here the development is concentrated. There is hardly ever a possibility to retreat to nearby areas where are more favourable thermal conditions. Therefore from a bioclimatological point of view the center of Karlsruhe, as a whole, is a problematic zone.

In sparsely built-up areas, where a great number of trees is growing, the thermal situation is noticeably better. For example the Waldstadt settlement can be considered as an ideal case. In comparison to other typical built-up areas the heat load values are at an optimum level here that is nearly the same as background stress. Moreover, stripes of greenery between the development guarantee varied conditions.

The large industrial areas in the north-west show thermal conditions that are not as bad as in densely built-up residential areas al though these are nearly entirely sealed. A small number of large buildings - as it is typical for industrial areas - facilitates a good ventilation which is mainly causing the moderate thermal conditions.

In the forest, days with heat load occur rather seldom, in the Hardtwald approximately about 17 times a year. And as the Hardtwald reaches into the loaded city center it has a certain importance, less due to the direct effect of relief on the thermal conditions than due to the fact that it is to leave the center for a better thermal environment.

For planning purposes about 120 areas have been marked by the municipial of Karlsruhe. They refer to new development areas as well as a concentration of already built-up areas, but in some cases also to an unsealing and a reduction of building. The effects of these land use changes are summarized in figure 10. It shows the differences in the bioclimate in days with a heat load between planned and current situation. In most cases an increasing of the heat load is expected. In order to obtain more detailed statements each single area has to be thoroughly investigated.

Berlin (ca. 3.34 mill. inhabitants)

With the example the city of Berlin a vast area of investigation is presented. The application of UBIKLIM by using a grid of 10mx10m did not seem practicable. Therefore the entire Berlin area was calculated with a grid width of 50m and only a section within the city of special interest was calculated with a 10m resolution. Subsequently the 10mx10m grid was nested into the 50mx50m grid. The result is shown in figure 11 : the bioclimate of the city of Berlin. There is obviously no single, i.e. joined heat island - in terms of human heat budget considerations - but rather a heat island archipelago. The settled area is markedly interlocked with its green surroundings thus partially reducing adverse effects on the bioclimate of the population due to settlement.

4. Conclusion

The climate of a city presents some of the most impressive examples of man-made climate modification. Knowledge of the interactions between the atmosphere and man- modified surfaces, however, is of value to the urban planner only when the bioclimatological significance of the changed atmospheric conditions is known. This requires an assessment (VDI, 1997). We also would like to know what can be done in the way of planning to safeguard health, well-being, and performance of the human being. Of special interest in the area of urban planning are meteorological conditions in the near-ground living space of the human being, i.e. the urban canopy-layer, which includes street canyons, parks and inner courtyards.

In particular there are two aspects of the urban environment which are of great importance: (1) the complex conditions of heat exchange between human beings and their environment, which depend on the meteorological variables air temperature, humidity, wind speed, and short- and long-wave radiant fluxes and additionally upon heat production, and the insulation value of clothing; and (2) air pollution, which depends upon sources, atmospheric diffusion, and transformation.

Coupling of meteorological boundary-layer models with physiologically significant energy balance models of the human being, taking additionally into account knowledge based on a condensation of the available results in urban climate research, as performed by UBIKLIM, shows the value of the approach. Present and future atmospheric conditions are simulated as a function of the planning variables which describe the settlement structure and are assessed with regard to health and well-being. The information can be used by urban planners, authorities, health professionals, and other decision makers in the area of environmental protection in order to reduce the negative effects of the changed climate found in cities and to guarantee healthy conditions for life and work.

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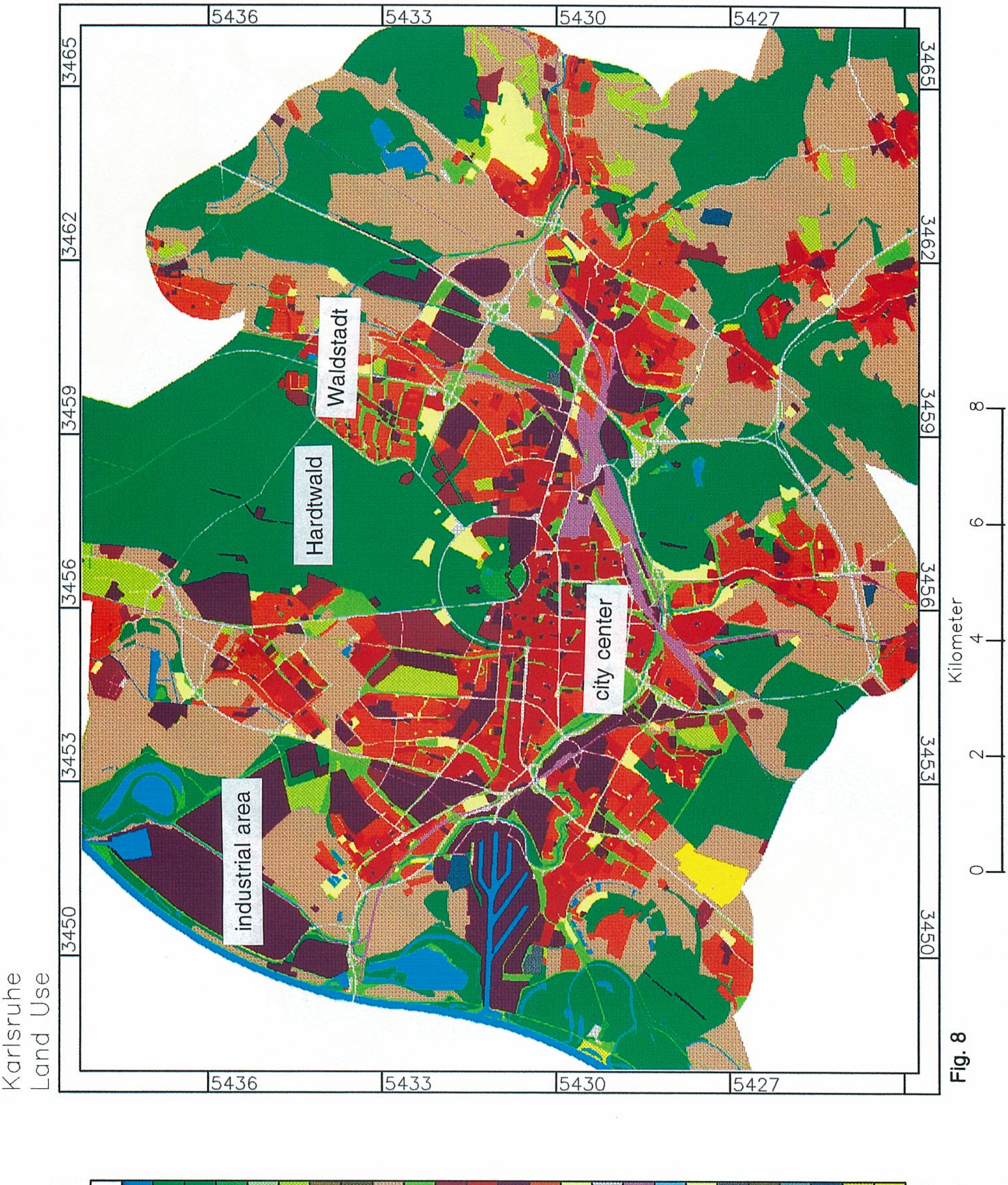
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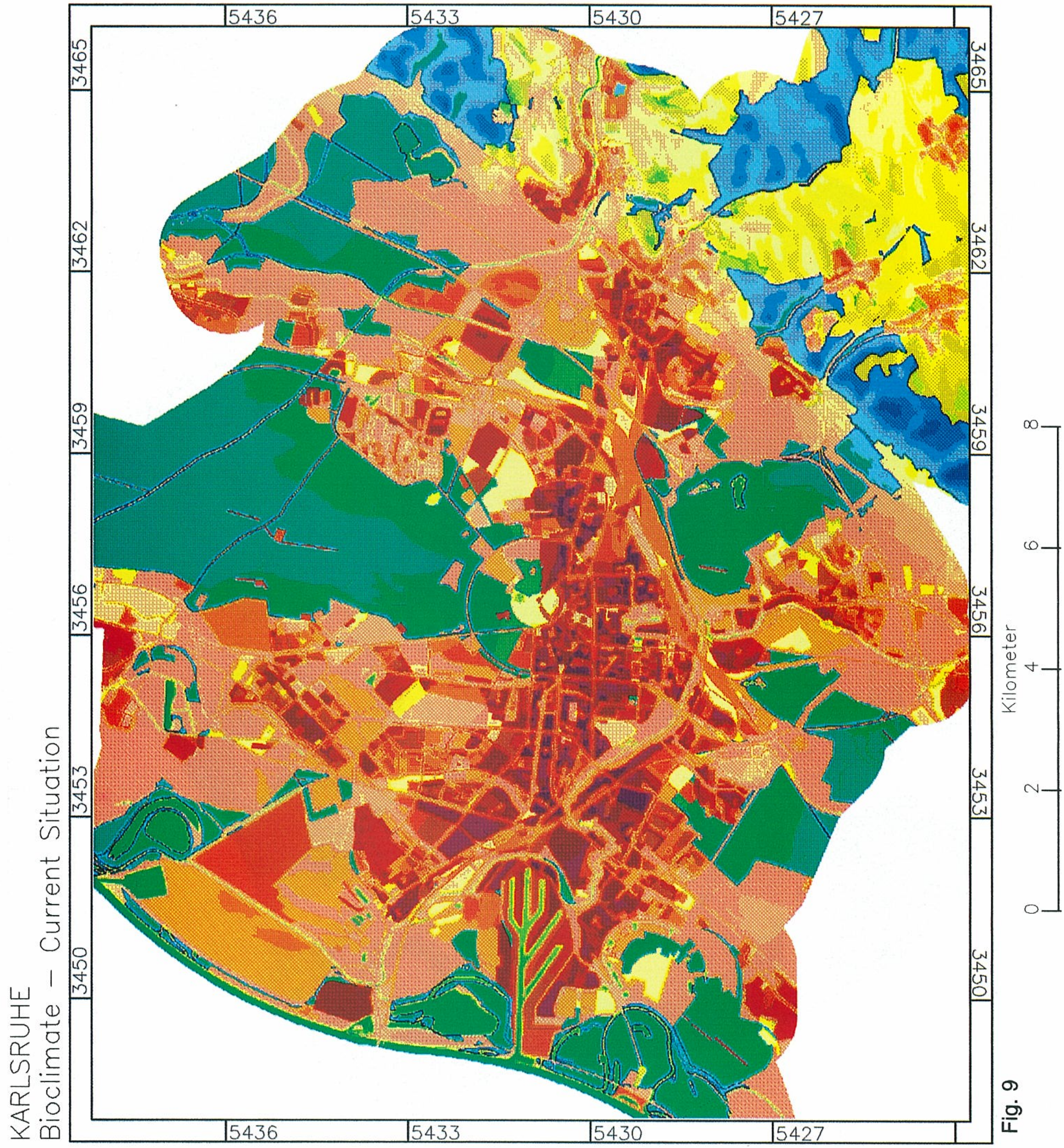
Fig. 8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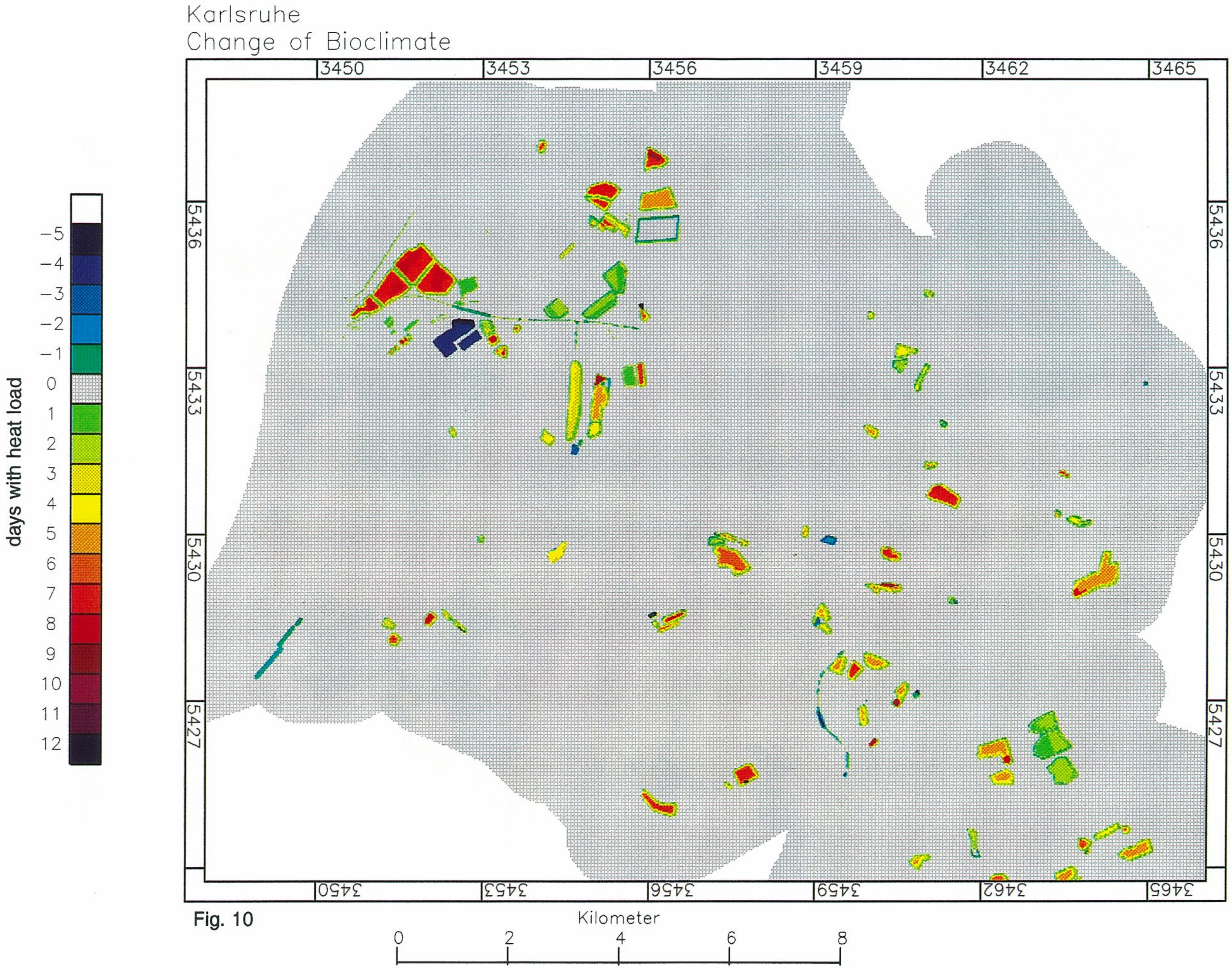
days with heat load

Fig. 9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3453
3456
3459
3462
3465
5436
5433
5430
5427
days with heat load
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Kilometer
0
2
4
6
8

Fig. 10

Berlin
Bioclimate

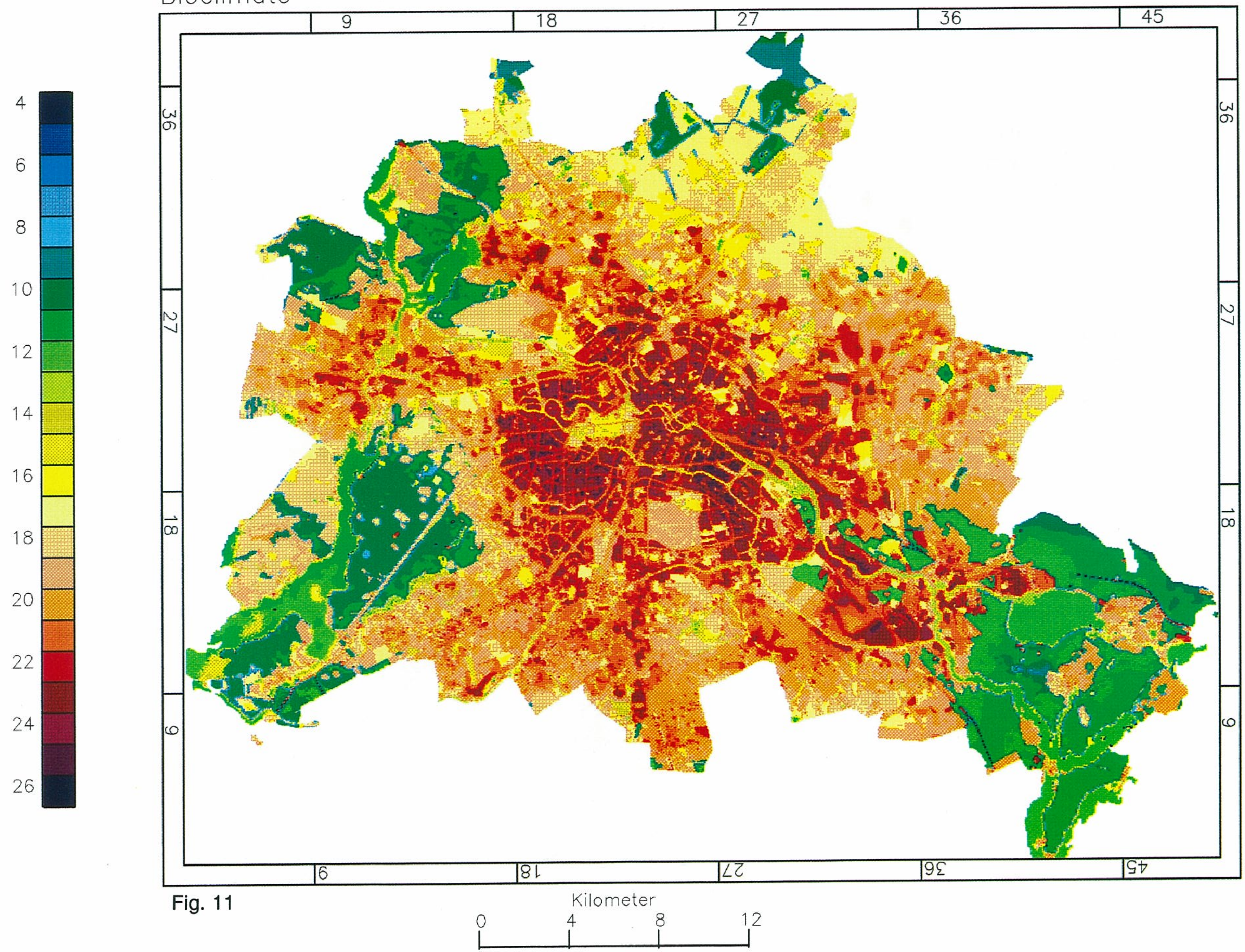

Fig. 11