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ON THE ASSESSMENT OF URBAN CLIMATE FACTORS IN THE LIGHT OF HUMAN BIOMETEOROLOGICAL ASPECTS

OCENA CZYNNIKÓW KLIMATU MIEJSKIEGO Z PUNKTU WIDZENIA BIOMETEOROLOGII CZŁOWIEKA

This paper considers the possibilities available for evaluating the effects of urban climate factors on city-dwellers. Examples of criteria for assessing the effects of the actinic, thermal and atmospheric hygiene complex are given and the application of these criteria to decision makers is explained. The significance of the various criteria is discussed.

INTRODUCTION

The tasks of urban planners in connection with climate and air hygiene include ensuring or securing optimum air pollution control in urban areas. All planning action must be well-founded. In many cases, the basic information required is provided by the results of research work in the field of applied urban climatology (Barlag 1993; Kuttler 1996, 1997). Assessment should be based on standard evaluation procedures which allow objective decisions. For this purpose, assessment criteria from the field of human bioclimatology can be used for the actinic, thermal and air hygiene complex of effects. Whereas it has been possible to improve thermal and air hygiene conditions in central European agglomerations with more or less success by planning intervention, this is not yet true of actinic conditions. However, there could be some changes in the near future as increasing importance is being given to the largely detrimental effects of short-term solar radiation on human beings. In view of the expected reduction in ozone concentrations in the stratosphere (Zellner 1993) and the resulting increase in the intensity of ultraviolet radiation (Frederick et al. 1991), the possibility of future health damage can no longer be excluded (Ambach, Blumenthaler 1993).

There are therefore pressing reasons for taking into account the actinic complex in urban planning work. The following paragraphs describe methods which can be used for assessing the bioclimatic parameters mentioned above especially in heavily populated industrial agglomerations. The following text refers only to conditions in Germany.

POSSIBILITIES OF ASSESSING THE ACTINIC COMPLEX

The actinic complex is the effect of ultraviolet radiation ($280 \text{ nm} < \lambda < 400 \text{ nm}$) from sun, sky and environment on human beings. This radiation accounts for about 7% of the overall energy in the solar radiation spectrum. Of the three bands of ultraviolet radiation (UV–A, UV–B and UV–C), UV–A radiation is especially important from the biological and medical points of view, with both positive effects (vitamin D_3 production) and detrimental impact (the risk of sunburn if unprotected skin is exposed for too long) (Koepke et al. 1997).

As skin damage normally only becomes evident after an extended period of sunbathing when it is already too late to take protective action, the recommendation that people should protect their skin is a major aspect of public health policy. In this connection, targeted predictions of UV radiation intensities and distributions are of crucial importance. Equation (1) (after SSK 1995) gives a basis for assessing the radiation intensity which causes sunburn (erythema producing intensity) on a horizontal surface:

$$E_{er} = \int_0^{\infty} E_\lambda(\lambda) \cdot s(\lambda)_{er,rel} \cdot d\lambda \qquad (1)$$

where:

- E_{er} – erythema producing radiation intensity,
- $E_\lambda(\lambda)$ – spectral radiation intensity,
- $s(\lambda)_{er,rel}$ – relative spectral sensitivity of erythema effect for UV erythema reaction,
- Unit – Wm^{-2}.

The erythema producing radiation, i.e. the dose, is given by equation (2):

$$H_{er} = \int_0^{t_1} E_{er} \cdot dt \qquad (2)$$

where:

H_{er} – erythema producing radiation,
E_{er} – erythema producing radiation intensity,
t_1 – exposure time,
Unit – Jm^{-2}.

For easier use in forecasts, especially with a view to informing the public, an ultraviolet index (UVI) based on the above equations has been introduced (Staiger et al. 1997). With this index, the daily maximum radiation dose can be calculated using the following equation:

$$UVI = E_{er} \cdot 40 \tag{3}$$

where:

E_{er} – erythema producing radiation intensity (Wm^{-2}),
40 – constant factor ($W^{-1}m^{+2}$),
Unit – (1).

Multiplication by the constant factor ensures that the value of the UVI is always between zero (minimum, e.g. winter value, no detrimental effect) and 12 (mean maximum in the tropics, maximum detrimental effect) (Kerr 1994) and has the dimension of 1. This means that the factors determined can easily be used by non-specialists in a way which is comparable with wind forces on the Beaufort scale.

Table 1 indicates UV threshold values for light skins based on conditions in central Europe, the risk of sunburn if the exposure times are exceeded and recommendations concerning protection. In Germany, UVI values up to 8 can be reached on high-radiation summer days. The UVI is determined by the German meteorological service using a regression model for total ozone concentration on the basis of a correlation between temperature and ozone partial pressure in various layers, a radiation transfer calculation for a cloud-free sky and a cloud cover correction factor. Forecasts are issued for a period of 48 hours from 12 UTC (Staiger et al. 1997). As daily forecasts are available for the area from 5 to 15°E and 45 to 55°N, it is possible to predict the UVI for any place within the area covered by the forecast.

These figures place decision makers in city planning departments and environmental agencies in a position to take appropriate action on the basis of visitor numbers and visit durations to protect visitors to open spaces against excessive summer solar radiation. This applies especially to squares, pedestrian precincts and playgrounds. The action available to protect the population against excessive ultraviolet radiation may include the provision of shelters, large trees, canopies and arcades planted with dense vegetation which is green in the summer.

Table 1

Recommendations for the protection of type II skins without prior tanning and sunburn in varius UVI ranges. Persons with a sensitive skin may suffer sunborn after shorter exposure (SSK 1995)

Zalecenia ochrony skóry typu II poprzednio nieopalonej i niepoparzonej słońcem w różnych przedziałach UVI. Osoby o skórze wrażliwej mogą ulec poparzeniu słonecznemu po krótkiej ekspozycji (SSK 1995)

UV index	Detrimental impact	Sunburn possible	Protection required
⩾8	very high	in less than 20 min	essential
7–5	high	in more than 20 min	required
4–2	moderate	in more than 30 min	recommended
⩽1	low	improbable	not required

POSSIBILITIES OF ASSESSING THE THERMAL COMPLEX

The thermal complex includes the conditions of heat transfer from the human body as a function of climatic conditions. Heat fluxes can be calculated using the energy balance equation which interconnects endogenic production and control factors with exogenic influences (Höppe 1984). In central European agglomerations, the main cause of thermal discomfort is excessive heat input, mainly in low-advection meteorological situations in the summer. There is considerable evidence of increased morbidity and mortality rates among city-dwellers (Landsberg 1981, Jendritzky et al. 1997). It is the task of preventive planning based on human bio-meteorological effects to detect unfavourable areas in terms of urban climatology and to indicate possibilities of eliminating or avoiding negative thermal impact.

In terms of bioclimatology, various values are used to describe the interaction between the various factors which affect human sensations of heat (e.g. discomfort index, effective temperature, heat stress index, equivalent temperature, etc. – Jauregui 1993).

However, these values are based solely on physical data and do not take into consideration the heat generated by the human body or the effect of clothing on thermal conditions. They should therefore be replaced by a thermal household model which also considers major physiological parameters (Jendritzky 1993). In this connection, a comfort equation based on Fanger (1982) has become widely used. This equation, which was originally used for assessing indoor climates, meets the requirements stated above. It is based on climate chamber tests with about 1300 persons whose sensations of heat were assigned to a psycho-physical scale. Using the value calculated, it was possible to define the thermal environment as it was perceived on average by the population considered. This value, the "Predicted Mean Vote" (PMV), predicts the percentage of the population considered which subjectively perceives discomfort under given thermal conditions.

Table 2

Meteorological and geographical inputs for the "Klima Michel" model (Jendritzky et al. 1990, modified)

Meteorologiczne i geograficzne wejście do modelu „Klima Michel"

Air temperature
Water vapour pressure
Wind speed at 1 m elevation
Cloud type and cover
Atmospheric turbidity
Solar constant
Coordinates
Date and time
Angular shares of surrounding areas
Albedo and emission of surrounding areas

The function developed by Fanger for calculating the PMV value corresponds to equation (4):

$$PMV = f(H/A_{Du}, I_{cl}, t_i, t_{mrt}, e, v_r) \quad (4)$$

where:

- H/A_{Du} – internal heat production referred to the surface area of a standard body (Wm^{-2}),
- I_{cl} – thermal insulation provided by clothing (clo), (1 clo = 0.155 KmW^{-1}),
- t_i – air temperature (°C)
- t_{mrt} – mean radiation temperature (°C),
- e – atmospheric water vapour pressure (hPa),
- v_r – relative wind speed (ms^{-1}).

In order to transfer the PMV to outdoor climatic conditions and to allow its use as a thermal reference value, it was extended to outdoor conditions using the "Klima-Michel-Model" (Jendritzky 1990). This is a model using the meteorological and geographic values listed in Tab. 2 which is based on a standard person (called "Michel", hence the name of the model – a male person, height 1.75 m, weight 75 kg, surface area 1.9 m). The original scale, which had four points has now been extended to form a 7-point scale. Table 3 shows the thermal perceptions and physiological stress perceptions for the various PMV values. This combined model has the advantage of also allowing statements concerning the thermal complex in definite areas, which is especially important in urban planning work.

Table 3

PMV discomfort factor, thermal perception and physiological stress (Jendritzky et al. 1990)

Czynnik dyskomfortu PMV, odczuwalność ciepła i stres fizjologiczny

PMV	Thermal perception	Physiological stress
–3.5	very cold	extreme cold stress
–2.5	cold	cold stress
–1.5	cool	moderate cold stress
–0.5	slightly cool	slight cold stress
0.0	comfortable	no stress
0.5	slightly warm	slight heat stress
1.5	warm	moderate heat stress
2.5	hot	severe heat stress
3.5	very hot	extreme heat stress

POSSIBILITIES OF ASSESSING THE AIR HYGIENE COMPLEX

The air hygiene complex includes factors such as the effects of solids, liquids and gases present in the atmosphere on human health.

The example of air pollution in western German conurbations shows that motor vehicle emissions are the main factor in air quality. Low pollutant sources and a closely knit network of roads with widely differing average traffic densities result in a very heterogeneous pattern of pollutant distribution over a very small area as a function of the pollutants considered and different types of land use. The concentrations produced are a function of the mass flow of pollutant output and the dilution potential of near-surface layers of the atmosphere. Figure 1 shows the pollutant concentration distributions determined for areas with representative types of land use in the city of Essen on the basis of measurement trips with high resolution in space and time made using a mobile laboratory. Measurements were made for three trace substances (NO, NO_2 and O_3). As regards the interpretation of the results, it should be remembered that this is a densely

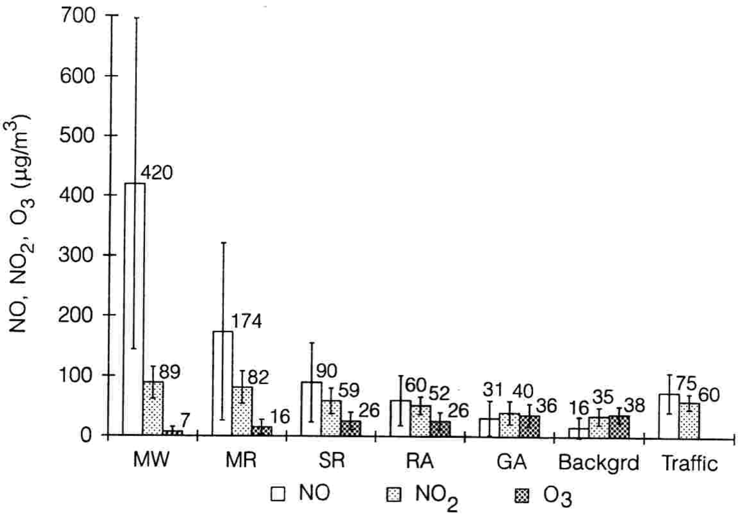

Fig. 1. NO, NO_2 and O_3 concentrations in different land use types in Essen, Germany (Air hygienic profile measurements, 12 trips, 1995) (Kuttler, Straßburger 1997) MW – Motorway, MR – Main road, SR – Side road, RA – Residential area, GA – Green area, Background and traffic stations of the North Rhine-Westphalia State Environment Agency

Rys. 1. Koncentracja NO, NO_2 i O_3 w Essen (Niemcy) na obszarach o różnych formach użytkowania (pomiary czystości powietrza, 12 serii, 1995) (Kuttler, Straßburger 1997) MW – autostrady, MR – drogi główne, SR – drogi boczne, RA – dzielnice mieszkaniowe, GA – obszary zielone, źródło i stacje pomiarowe – Federalna Agencja Środowiska Północnej Nadrenii-Westfalii

populated area where many people live in the immediate vicinity of roads with heavy traffic and are exposed to high pollutant concentrations. The distribution of NO values on motorways and other major roads resulted in by far the highest concentrations in the city area. On average, ozone concentrations on such roads are insignificant because of the very low NO_2/NO ratio of 0.2 or 0.5 (Kuttler, Strassburger 1997). However, the situation is very different on minor roads and in residential areas, where NO and NO_2 concentrations are lower but ozone levels are higher. In green spaces, ozone concentrations reach the highest average values for a number of reasons including the higher NO_2/NO ratio of 1.3. The average trace substance concentrations also shown in Fig. 1 (on the right) are based on values measured by fixed stations operated by the state of North Rhine-Westphalia (averages of the values measured by three stations over the period of the test trips). These values give little indications of pollutant concentrations in the areas concerned with different types of land use. To a large extent, assessment of the health aspects of individual atmospheric pollutants is governed by German and European standards. However, in terms of their application to pollution problems in cities, there are a number of deficiencies in the criteria defined (Tab. 4). Following Mayer (1990), these deficiencies may be summarized as follows. Maximum values have not been defined for all key pollutants. In addition, most of the criteria defined refer to average members of the population and do not consider population groups (such as small children and old people) with relatively unstable health. These standards also fail to take into consideration the high mobility of city-dwellers. In other words, the corresponding dose of atmospheric pollutants to which a person is exposed over a period of time is not taken into account. It was already pointed out that the overall assessment of urban air pollution plays an important role in planning decisions. It is true that an overall assessment of this type can be made on the basis of various air quality indices. However, these indices only reflect concentrations of certain key substances. For example, the LBI index, one of the most widely used air quality indices in Germany (Baumüller, Reuter 1995) only reflects SO_2, NO_2 and dust concentrations on the basis of TA-Luft, the German clean air regulations. Moreover, SO_2 and dust concentrations are not very appropriate air quality indicators for western German conurbations because concentrations of these pollutants are now normally very low. Unfortunately, TA-Luft does not lay down any maximum values for ozone or for benzene, toluene or xylene (BTX), hydrocarbons emitted mainly by road vehicles, which could be used for comparison with values measured. In other words, these substances, which are now the most significant atmospheric pollutants, are not reflected by air quality indices and measured values can only be compared with EC values or limits defined by the state atmospheric pollution committee. This is extremely unfortunate as it is therefore not possible to make an effective overall assessment of the type which is often wished and sometimes essential.

Table 4

Air hygiene assessment criteria (various sources)

Kryteria oceny czystości powietrza (różne źródła)

IW1 (long-term exposure values from TA-Luft (1993)
IW2 (short-term exposure values from TA-Luft (1993)
MIK (maximum concentration values) from VDI code of practice 2310 (1974)
Smog regulations (winter smog)
Summer smog law
EC limits and guidelines
LBI air quality index for long-term, short-term and daily exposure
Air quality standards (KÜHLING 1986)
WHO air quality guidelines (1987)
Air quality in health resorts (Deutscher Bäderverband 1987)

In view of the need for a standard European procedure for air quality assessment, a concerted effort should be made to develop a pan-European solution as soon as possible.

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STRESZCZENIE

W artykule rozważono możliwości oceny wpływu czynników miejskich na mieszkańców miast. Podano przykłady kryteriów dla oszacowania zespołu aktynicznego, termicznego i czystości atmosfery. Wyjaśniono zastosowanie tych kryteriów dla potrzeb decydentów. Przedyskutowano znaczenie różnych kryteriów.