ASSESSMENT OF ATMOSPHERIC IMPACTS ON HUMAN BEINGS IN A RE-GIONAL SCALE

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Abstract
Methods of human-biometeorology have to be applied for the assessment of atmospheric impacts on human beings. Among the human-biometeorological effective complexes two are of great importance in the regional scale: the thermal effective complex and the air quality effective complex. A procedure for the physiologically significant assessment of the thermal environment is explained. It is based on thermal indices which are derived from the human energy balance. As an exemplary result a bioclimate map of Greece for the summer month August is presented which shows the pronounced spatial distribution of mean daily values of the thermal index Physiological Equivalent Temperature PET. With respect to the air quality effective complex, standards for the assessment of single air pollutants exist worldwide. In addition, approaches for statistical air stress indices and impact-related air quality indices were developed. Based on three-year air pollutant data from three different sites in SW Germany, the frequency distribution of the air stress index ASI_{BW} is compared with the frequency distribution of the new air quality index DAQx. Both indices are on a daily basis. The varying forms of both frequency distributions are mainly caused by the impact-related concentration ranges of single air pollutants which are typical of air quality indices. Especially ozone has a stronger influence on the determination of values of air quality indices.

1. Introduction

There are a lot of questions on the impacts of the atmospheric environment on human beings which are focussed on the regional scale (e.g. landscape planning). To get answers, methods of human-biometeorology have to be applied [1]. Among the human-biometeorological effective complexes two are of great importance in the regional scale: the thermal effective complex and the air quality effective complex. They have to be assessed in a human-biometeorologically significant manner. The objective of this article is twofold:

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(1) to give a brief overview of assessment methods and (2) to discuss exemplary results.

2. Methods for the Human-biometeorological Assessment of the Environment

2.1 THERMAL ENVIRONMENT

The thermal effective complex deals with the influences of the thermal environment on the well-being and health of human beings. The basis is the close relationship between the human thermoregulatory mechanism and the human circulatory system. For the physiologically significant assessment of the thermal environment, some thermal indices are available which are derived from the human energy balance [2]. The characteristics of the method for the human-biometeorological assessment of the thermal environment are illustrated in Figure 1.

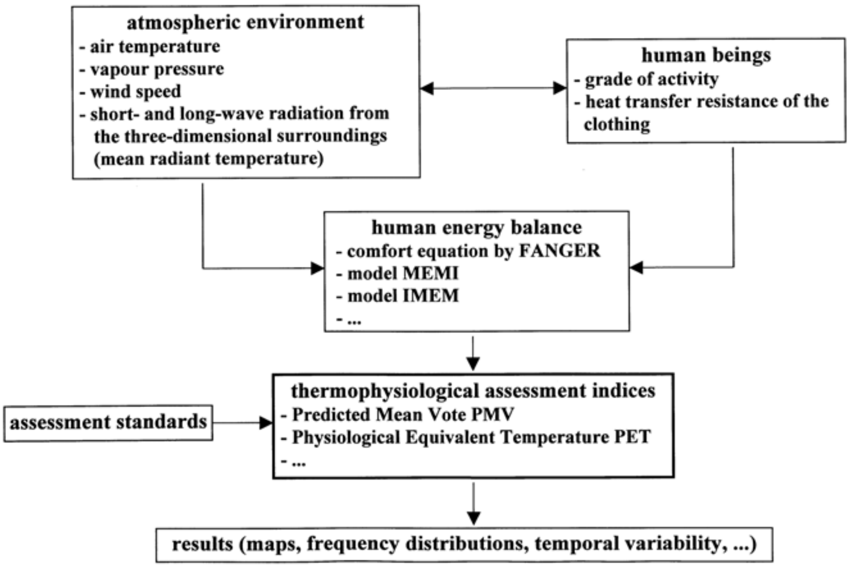

Figure 1. Flowchart for the human-biometeorological assessment of the thermal environment.

2.2 AIR QUALITY CONDITIONS

A general overview of the different procedures for the human-biometeorological assessment of the air quality conditions is given in Figure 2. Standards for the assessment of single air pollutants exist in almost every country of the world, e.g. in EU directives. However, these standards are insufficient in view of the persistent demands (e.g. from planners) for the assessment of the air quality, which is not limited to a single air pollutant. Therefore, indices on the basis of routinely monitored air pollutants were developed. They can be categorized into two groups [3]. The first group includes indices, which are only statistical and have no direct relation to the well-being and health of human beings. They indicate mainly the content of air pollution in the ambient air and, therefore, are called air stress indices ASI. They can be calculated according to:

$$ASI = \sum_{i=1}^{n} \left[\frac{C}{R}\right]_i \qquad \text{resp.} \qquad ASI = \frac{1}{n} * \sum_{i=1}^{n} \left[\frac{C}{R}\right]_i \tag{1}$$

with a symbol description in Table 1.

TABLE 1. Description of symbols in (1).

	mean stress (year, day)	**short-term stress**
n	number of air pollutants	number of air pollutants
C	time specific concentration of the air pollutant i	number of cases per calendar year: air pollutant specific limit values are exceeded
R	time specific reference (limit) value of the air pollutant i	number of cases per calendar year: air pollutant specific limit values are not to be exceeded

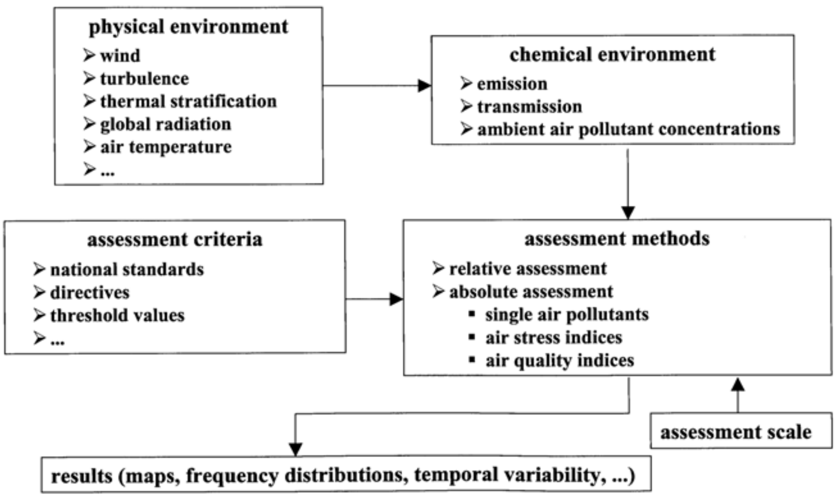

Figure 2. Flowchart for the human-biometeorological assessment of the air quality conditions.

Examples for air stress indices are [3]:

** planning-related air stress index ASI_1 for mean stress, developed by the Office of Environmental Protection, Division Urban Climate, City of Stuttgart, Germany:

$$ASI_1 = \frac{1}{4} * \left(\frac{C(SO_2)}{20\ \mu g/m^3} + \frac{C(NO_2)}{40\ \mu g/m^3} + \frac{C(PM_{10})}{40\ \mu g/m^3} + \frac{C(benzene)}{5\ \mu g/m^3} \right)$$

(2)

C: arithmetical annual mean values (µg/m^3); limit values from EU directives

** planning-related air stress index ASI_2 for short-term stress, developed by the Office of Environmental Protection, Division Urban Climate, City of Stuttgart, Germany:

$$ASI_2 = \frac{1}{4} * \left(\frac{N(SO_2)}{24} + \frac{N(NO_2)}{18} + \frac{N(PM_{10})}{35} + \frac{N(CO)}{1} \right) \tag{3}$$

N: number of cases per calendar year: air pollutant specific EU limit values are exceeded; reference values: number of cases per calendar year: air pollutant specific EU limit values are not to be exceeded (SO_2: 350 µg/m^3 (1 h mean value), NO_2: 200 µg/m^3 (1 h mean value), PM_{10}: 50 µg/m^3 (daily mean value), CO: 10 mg/m^3 (highest daily running 8 h mean value))

** air stress index ASI_{BW} on a daily basis, developed by the Federal State Institute for Environmental Protection Baden-Wuerttemberg, Karlsruhe, Germany:

$$ASI_{BW} = \frac{C(SO_2)}{350\,\mu g/m^3} + \frac{C(CO)}{10\,mg/m^3} + \frac{C(NO_2)}{200\,\mu g/m^3} + \frac{C(O_3)}{180\,\mu g/m^3} + \frac{C(PM_{10})}{50\,\mu g/m^3}$$

(4)

C(SO_2), C(NO_2), and C(O_3): highest daily 1 h mean values (µg/m^3), C(CO): highest daily running 8 h mean value (mg/m^3), C(PM_{10}): daily mean value (µg/m^3); limit values from EU directives

In contrast to ASI_{BW}, a graded assessment scale (Table 2) is available for the air stress indices ASI_1 and ASI_2 [3], which e.g. can serve as basis for planning specific recommendations with respect to the air quality.

TABLE 2. Assessment of the air quality conditions on the basis of ASI_1 and ASI_2 [3].

ASI_1: no single air pollutant exceeds the corresponding limit value		
ASI_2: no single air pollutant shows a higher number of cases per calendar year with air pollutant specific limit values are exceeded than the permitted number		
level I	very low air stress	ASI_1, $ASI_2 < 0.2$
level II	low air stress	$0.2 \leq ASI_1$, $ASI_2 < 0.4$
level III	moderate air stress	$0.4 \leq ASI_1$, $ASI_2 < 0.6$

level IV	distinct air stress	$0.6 \le ASI_1, ASI_2 < 0.8$
level 5	strong air stress	$ASI_1, ASI_2 \ge 0.8$
ASI_1: no less than one air pollutant exceeds the corresponding limit value		
ASI_2: no less than one air pollutant shows a higher number of cases per calendar year with air pollutant specific limit values are exceeded than the permitted number		
level VI	extreme air stress	independent of ASI_1 and ASI_2

Impact-related indices which are called air quality indices constitute the second group of indices for the assessment of the air quality effective complex. Such indices are very rare, because it is difficult to quantify the impacts of air pollutants on the well-being and health of human beings. The methodology of air quality indices is to assign concentrations of ambient air pollutants to different air pollutant specific ranges. The air quality index itself is represented by the highest index class among the considered air pollutants (Figure 3). The relation to the impact on human beings is given by different classified ranges of air pollutant concentrations, which are derived from epidemiological and toxicological investigations.

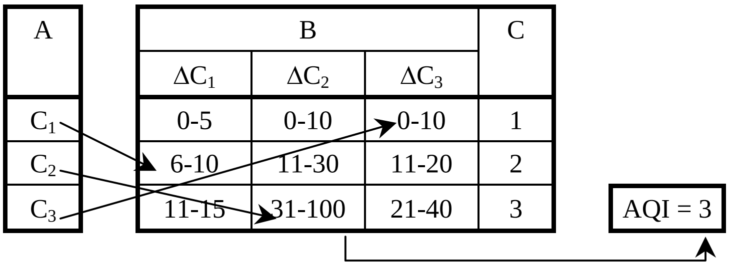

Figure 3. Method for the determination of impact-related air quality indices AQI [3, 4]; A: current concentrations C of air pollutants 1, 2, and 3; B: impact-related concentration ranges ΔC of air pollutants 1, 2, and 3; C: index class for single air pollutants.

A new impact-related air quality index obtained on a daily basis and abbreviated as DAQx (**D**aily **A**ir **Q**uality Inde**x**) was recently developed and tested by the Meteorological Institut, University of Freiburg, and the Research and Advisory Institute for Hazardous Substances, Freiburg, Germany [3, 4]. DAQx considers the air pollutants SO_2, CO, NO_2, O_3, and PM_{10}. To enable a linear interpolation between index classes, DAQx is calculated for each air pollutant by

$$DAQx = \left[\left(\frac{DAQx_{up} - DAQx_{low}}{C_{up} - C_{low}} \right) * \left(C_{inst.} - C_{low} \right) \right] + DAQx_{low} \qquad (5)$$

with $C_{inst.}$: highest daily 1 h concentration of SO_2, NO_2, and O_3, highest daily running 8 h mean concentration of CO, and mean daily concentration of PM_{10};

C_{up}: upper threshold of specific air pollutant concentration range (Table 3); C_{low}: lower threshold of specific air pollutant concentration range; $DAQx_{up}$: index value according to C_{up}; $DAQx_{low}$: index value according to C_{low}.

TABLE 3. Assignment of ranges of specific air pollutant concentrations to DAQx values and DAQx classes inclusive of classification names according to school marks [3, 4]

SO_2 (µg/m³)	**CO (mg/m³)**	**NO_2 (µg/m³)**	**O_3 (µg/m³)**	**PM_{10} (µg/m³)**	**DAQx value**	**DAQx class**	***classification***
0 – 24	0.0 – 0.9	0 – 24	0 – 32	0.0 – 9.9	0.5 – 1.4	1	*very good*
25 – 49	1.0 – 1.9	25 – 49	33 – 64	10.0 – 19.9	1.5 – 2.4	2	*good*
50 – 119	2.0 – 3.9	50 – 99	65 – 119	20.0 – 34.9	2.5 – 3.4	3	*satisfactory*
120 – 349	4.0 – 9.9	100 – 199	120 – 179	35.0 – 49.9	3.5 – 4.4	4	*sufficient*
350 – 999	10.0 – 29.9	200 – 499	180 – 239	50.0 – 99.9	4.5 – 5.4	5	*poor*
≥ 1000	≥ 30.0	≥ 500	≥ 240	≥ 100	≥ 5.5	6	*very poor*

3. Results for the Human-biometeorological Assessment of the Environment

3.1. THERMAL ENVIRONMENT

In the meantime, some investigations were performed which use thermal indices like PMV or PET for the human-biometeorological assessment of the thermal environment in different scales. Results from case studies [2] enables a process analysis, e.g. in the form of regressions between PET as thermal index and meteorological input parameters such as single radiative fluxes, mean radiant temperature, air temperature, or vapour pressure. For calculating the mean radiant temperature, the human-biometeorological radiation model RayMan was developed by Matzarakis et al. [5], which is well suited for the application in different environments, esp. within urban structures, because it considers various complex horizons. In addition, thermal indices like PMV, PET or SET* are output variables of RayMan.

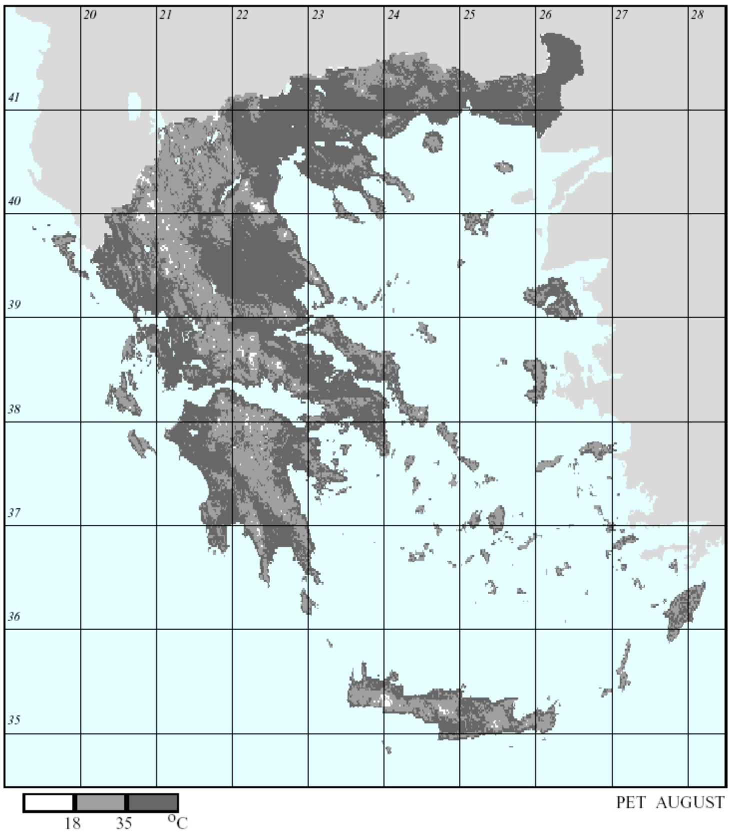

Figure 4. Spatial distribution of mean daily values of Physiological Equivalent Temperature PET in Greece at 12 UTC in August.

As an example for bioclimate maps, the spatial distribution of mean daily PET values in Greece at 12 UTC in August (Figure 4) shows the influences of different site factors like elevation or distance to the coast, which are well pronounced. August is in Greece one of the summer months with the highest heat stress conditions for the population. For example, all regions below 600 m asl show high heat stress. There are comparatively large spatial differences between the areas with high heat stress. On the islands of the Aegean and Ionian Sea, the heat stress conditions are somewhat lower than those obtained in the interior parts of the country. Extreme heat stress is obtained for lower parts of Greece (e.g. in Thessaly, Macedonia, in the western part of Sterea Ellada, and the southern part of Epirus) as well as for the coastal areas that are covered with land masses or closed gulfs. Most islands also fall into this category, although conditions with strong heat stress are much lower in relation to the mainland. This is due to the influence of cool, dry Etesian winds in the Aegean Sea and the development of regional wind systems in the Ionian Sea [2, 6].

3.2. AIR QUALITY CONDITIONS

To investigate the sensitivity of indices for the assessment of the air quality conditions in a regional scale, frequency distributions for ASI_{BW} as an exponent of air stress indices and DAQx as an exponent of air quality indices were calculated for three sites with official air quality monitoring stations in SW Germany in the period 1996-1998: Schwaebische Alb (far from emissions on an agricultural plateau), Ehingen (mean size city, 24.000 residents, with through roads and industry), and Mannheim–Sued (bigger city, 320.000 residents, with traffic and industry emissions typical of urban conurbations). ASI_{BW} as well as DAQx are indices on a daily basis. Since ASI_{BW} has no relation to the impact on human beings, six LBI_{BW} classes were statistically defined on the results of three-year daily values (class I: $ASI_{BW} < 0.5$; class II: $0.5 \leq ASI_{BW} < 1.1$; $1.1 \leq ASI_{BW} < 1,7$; $1.7 \leq ASI_{BW} < 2.3$; $2.3 \leq ASI_{BW} < 2.9$; $ASI_{BW} \geq 2.9$).

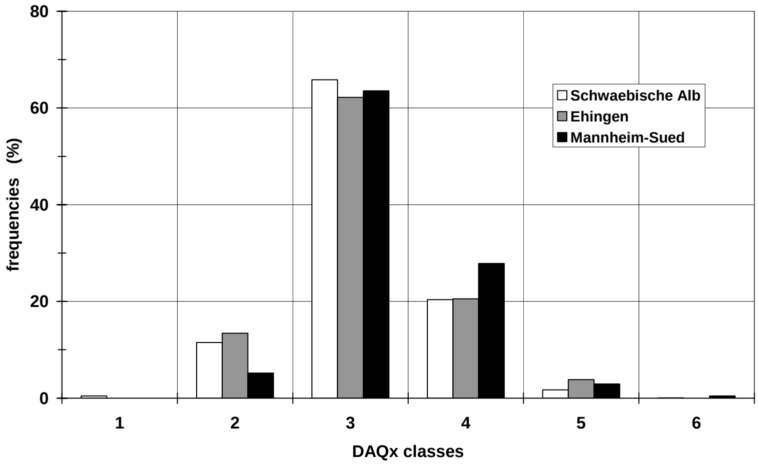

Figure 5. Frequencies of DAQx classes at three different sites in SW Germany in the period 1996-1998 [3, 4].

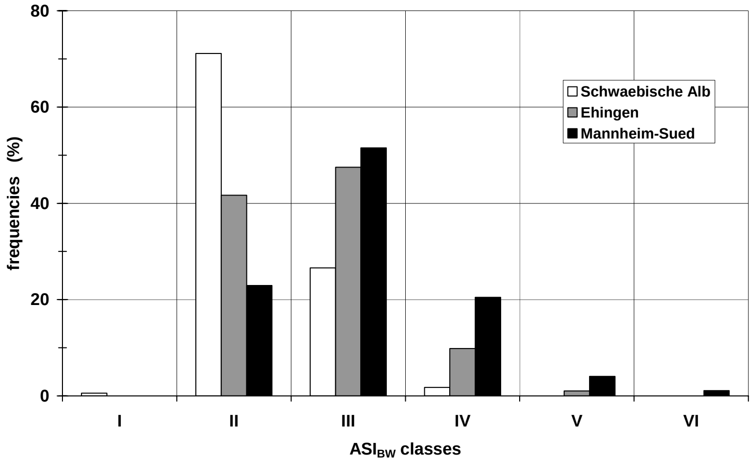

Figure 6. Frequencies of ASI_{BW} classes at three different sites in SW Germany in the period 1996-1998 [3, 4].

At first sight, the forms of both frequency distributions (Figures 5 and 6) differ. The results for ASI_{BW} reflect the qualitative assessment of the air pollution conditions by human beings so far, i.e., air pollution decreases with increasing distance to the emission sources. O_3, which exhibits generally higher values in areas with no anthropogenic emissions, is mainly responsible for the changed form of the frequencies of DAQx clas-ses.

4. Conclusions

For the assessment of the thermal environment on human beings in a regional scale, human-biometeorology provides well suited thermal indices on the basis of the human energy balance. Aside from single air pollutant standards, air stress indices and air quality indices enable an additional assessment of the air quality conditions, which is primarily not limited to single air pollutants. The application of air stress indices or air quality indices depends on the specific objectives of the investigation.

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