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The Significance of Country Breezes for Urban Planning

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ABSTRACT

The increase of horizontal air exchange in agglomeration areas, especially during weather conditions with low wind velocities, is crucial in urban planning.

In this connection the mesoscale circulation induced by an urban heat island, i.e., a country breeze ('Flurwind'), is of great importance for the improvement of the ventilation in built-up areas.

An insight into the characteristic flow patterns of country breezes and their implications for urban planning purposes necessitates continuous measurements.

This paper presents an analysis of recorded wind data at five stations over a period of 16 months. The area under investigation was Bochum, a town located in the heart of the densely populated Ruhr industrial region in the Federal Republic of Germany.

The results show that country breezes occurred during 10% of the total measuring time in the city of Bochum. The records, including the spatial and temporal structure of country breezes, confirm that this kind of wind regime must be regarded as an essential element in urban planning.

1. INTRODUCTION

The urban climate is significantly determined by the limitation of air exchange caused by the presence of high roughness parameters. Due to limited circulation, the heat generated by the city and pollutants emitted by near-surface sources are insufficiently dispersed, increasing the environmental impact on the residential population. The effects of inadequate ventilation are critical during periods of extremely low prevailing winds and high radiation; in fact, these problems have so far remained unsolved by urban planners.

Meso-circulation induced by the urban heat-island could offer considerable potential for the improvement of air quality in cities by enhanced circulation, especially during phases of low air exchange, if the structures of cities were designed to exploit these air flows.

Air-flow patterns may be anticipated to be different during the day and at night, for the roof surfaces of buildings are the hottest part of a town when the sun is shining, while the ground levels of street canyons are the warmest at night. As friction effects change with increasing altitude, the altitude of peak country breeze frequencies will also be different during the day and at night. In fact the urban atmosphere may be stratified vertically. Oke [1], for instance, defined an urban canopy layer (UCL) and an urban boundary layer (UBL) (Fig. 1). The urban canopy layer develops between ground level and the building roof level. Its characteristics are chiefly determined by the increased surface caused by buildings and their roughness. Circulation in the adjacent urban boundary layer is controlled by the thermal and mechanical properties of the city. The urban boundary layer finally merges at an altitude of several hundred metres into the troposphere, in which air flow is controlled by atmospheric pressure gradients and Coriolis acceleration.

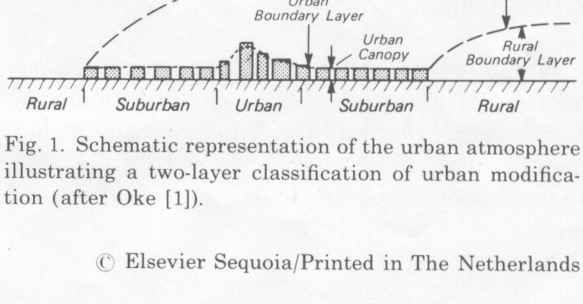

Fig. 1. Schematic representation of the urban atmosphere illustrating a two-layer classification of urban modification (after Oke [1]).

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The discussion of country breeze effects in this paper is limited to the urban canopy layer, being the residential area of the urban population and thus the subject of research for improved ventilation conditions.

2. HISTORICAL REVIEW

Country breezes were first observed in London (U.K.) at the beginning of the 20th century by Carpenter [2], who published visual fog and wind data recorded by the London fire brigade. Schmauss [3] and Eckardt [4] wrote about multi-directional air flows from rural areas into the cities of Dortmund (F.R.G.) and Essen (F.R.G.) under certain weather conditions. These early German reports on country breezes were followed by a paper by Sperk [5], who concluded from changes in the frequency of wind directions in Nuremberg (F.R.G.) following the resiting of the meteorological stations that country breezes exist. Okita [6] inferred from rime on trees that nocturnal winds flow into the city of Ashikawa in Japan. A centripetal wind system was also found by Band [7] in the Cologne area (F.R.G.) on observing the directions of fumes from smoke stacks.

The first quantitative data were published by Emonds [8]. He demonstrated the existence of a country breeze system by mobile laboratory measurements in the city of Bonn (F.R.G.), and recorded maximum country breeze speeds of 2 m/s for prevailing wind velocities of less than 3 m/s.

Similar results were published by Pooler [9] for Louisville (U.S.A.), Findlay and Hirt [10] for Toronto (Canada), Georgii [11] for Frankfurt (F.R.G), Dannevik *et al.* [12] for St. Louis (U.S.A.), Lee [13] for London (U.K.), Shreffler [14] for St. Louis (U.S.A.), Fujibe and Asai [15] for Tokyo (Japan), Stock *et al.* [16] for Dortmund (F.R.G.) and Kuttler [17] for Dortmund (F.R.G.).

3. DEFINITIONS

Visual observations and short-term experimental data may confirm the existence of country breezes, but they do not provide an insight into their distribution in time and space. Their value for urban planning is limited for this reason. A long-term survey, on the other hand, recording wind data at meteorological stations for a period of at least one year, would no longer merely supply random data but a wealth of statistically sound data for country breeze analysis, and would create a reliable data base for urban planning.

Reliable information recorded at permanent stations and processed by statistical techniques for urban planning presupposes a reliable definition of the wind pattern that is being studied. Using the criteria described in the literature [1–17], country breezes may be defined as 'intermittent slow near-ground air flows from rural areas into the city centre independent of overlying air-flow regimes which are only induced by temperature differences between the town and the surrounding rural area'.

Country breezes are part of a relatively unstable system with flow patterns which would tend to indicate preferred wind directions rather than continuous mono-directional air movements. The instability of the system is integrated directly into the definition of country breezes given below.

In the Bochum study, stations were arranged on a circle around the city centre (Fig. 2); with the city centre in a central position, data of each station were compared with respective data of a station located beyond the city centre (Table 1).

Using the criteria defined by Kiese and Otto [18], centripetal conditions were assumed to exist if:

(a) two paired stations both recorded air flows from the semicircle bisected by the centre-to-station line towards the city centre;

(b) the difference in the directions of winds entering the semicircle was at least 50°; and

(c) the wind speed at the two stations was below 2 m/s.

Several stations were paired, because it was considered adequate for the interconnecting line between the two stations to pass through the thermal centre (dependent on the density of buildings and on the ratio between natural and coated ground surfaces) rather than through the geographical centre of the city (Table 1).

Country breeze conditions were assumed to exist if at least one pair of stations recorded a phenomenon satisfying the above criteria.

4. THE COUNTRY BREEZE SYSTEM OF THE CITY OF BOCHUM

Country breeze conditions in the city of Bochum were measured during the period from May 1987 to August 1988 [19].

The city of Bochum is situated in the centre of the Ruhr area in North-Rhine Westphalia (F.R.G.). Its surface area of approximately 145 km^2 is inhabited by about 370 000 people. The population density is almost 2800 people/km^2. The average height of buildings in the downtown area is about 30 m, equivalent to an estimated roughness length (dynamic roughness) of nearly 1 m [20]. The urban area is located in a region of smooth topographic features.

A network of five stations arranged on a circle around the centre of Bochum was used to measure country breezes. Each station was equipped with a Woelfle anemometer, which recorded average hourly surface wind data continuously. Each anemometer was installed at a height of 4.5 m above ground level. Five pairs of stations satisfied the conditions defined in Section 3 (Fig. 2).

Wind data were recorded for a total of approximately 11 750 h (16 months) to define the Bochum surface wind system regarding its geographical distribution and its distribution in time.

The frequency of country breeze conditions is, of course, the most crucial question. As Table 1 shows, country breeze conditions were prevailing during 10.1% of the total measurement period. Country breezes even accounted for 18.5% of the total period during which the average wind speed measured at the five stations was $\leqslant 2$ m/s.

Country breezes were actually recorded both under anticyclonic and cyclonic conditions as well as in the case of other local wind

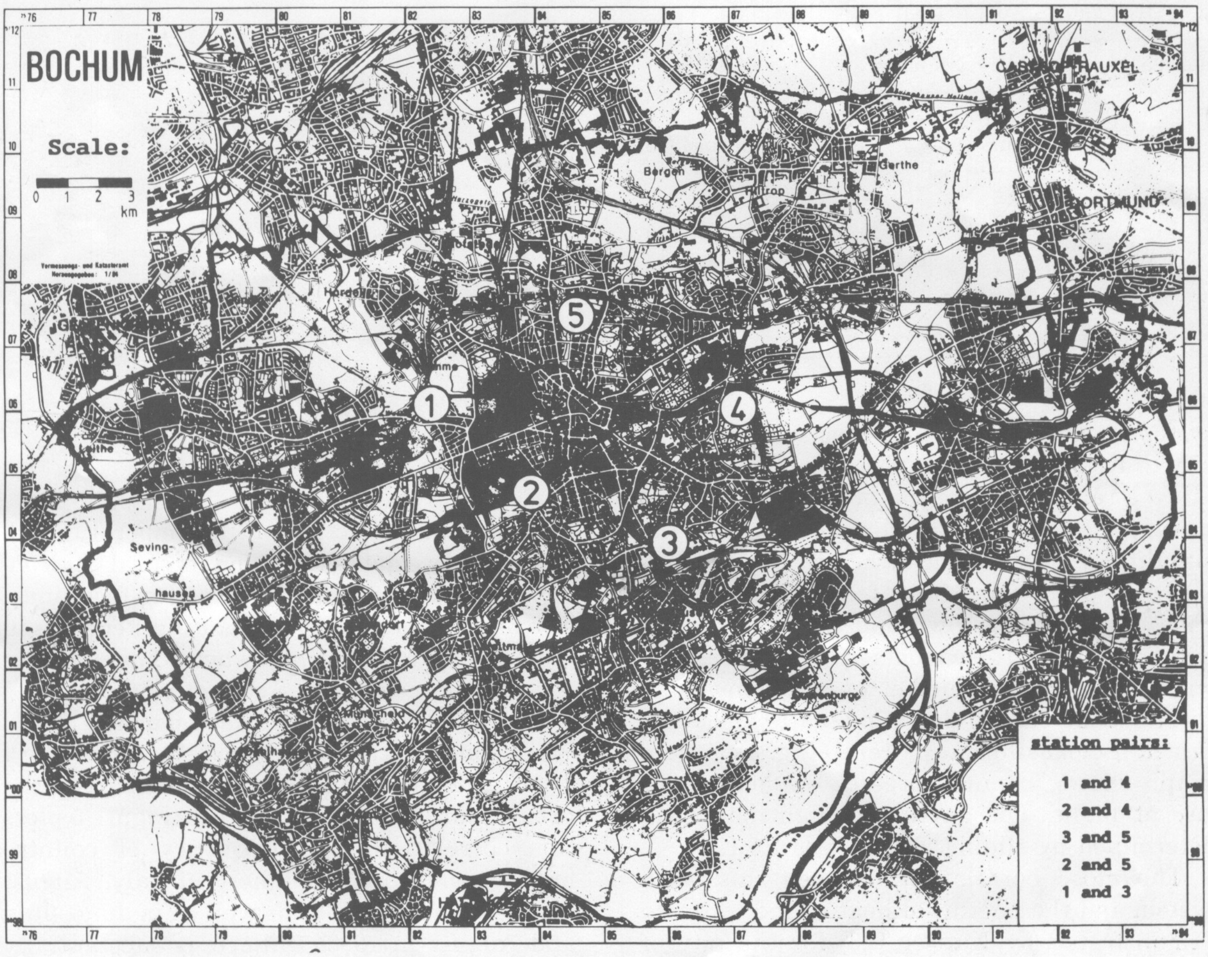

Fig. 2. Location of stations around the city of Bochum (measuring period from May 1987 to August 1988).

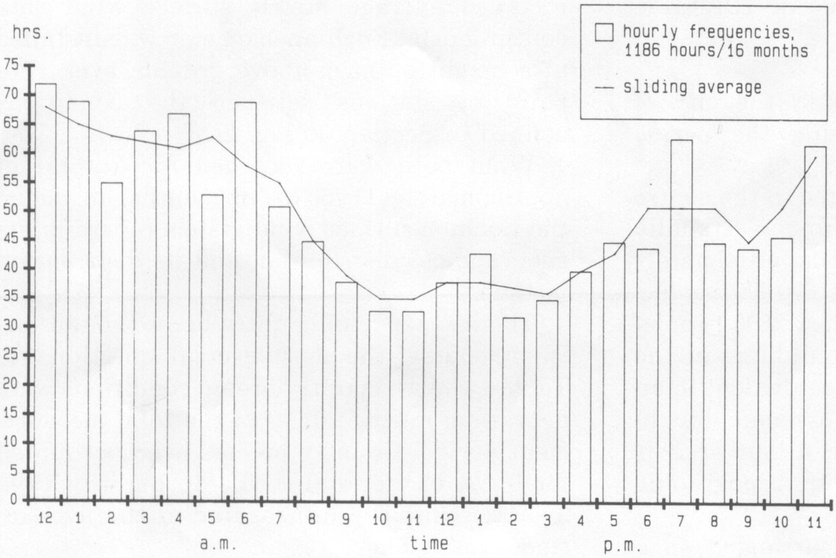

Fig. 3. Daily distribution of country breeze hours in the city of Bochum (measuring period from May 1987 to August 1988).

TABLE 1

Total number of country breeze hours (measuring period from May 1987 to August 1988)

Station pairs	Country breezes	
	Country breeze hours (h)	Part of total time (%)
Total	1186	10.1
1/4	200	1.7
2/4	451	3.8
3/5	325	2.8
2/5	394	3.4
1/3	194	1.7

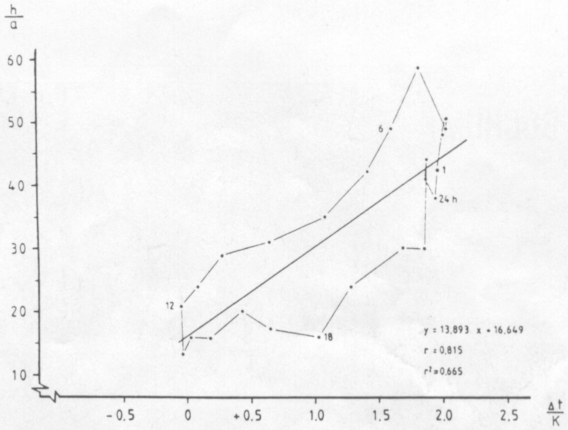

Fig. 4. Dependence of country breeze hours on the heat-island intensity in the city of Dortmund (after Kuttler [22]) (measuring period from January to December, 1985).

systems, such as the land–sea system of the city of Kiel (F.R.G.) [21]. These criteria do not allow a reliable prediction of local air flows to be made. Even under cyclonic conditions, the stability of atmospheric stratification, prevailing low-speed winds and temperature differences between the town and the surrounding rural area seem to be sufficient to induce local wind systems on a number of occasions.

The analysis of the wind data also confirmed a clear diurnal pattern (Fig. 3). As the graph shows, country breezes predominantly rise at night. The daytime-to-nighttime ratio determined by sliding averages is 1.5:1.

The close correlation between this wind system and the nocturnal heat island was also demonstrated by Kuttler [22] for the city of Dortmund. Figure 4 shows the country breeze frequency as a function of the temperature difference between the town and its rural environment obtained by a linear regression technique. The night hours with the highest differences in temperature are the times when country breeze conditions occur most frequently.

For the same reason, the frequency of the conditions of this wind system varies as a function of the changes in the intensity of the urban heat island over the year. Figure 5 plots this correlation. The frequency of country breeze conditions is highest in July, August and September in 1987 as well as in June, July and August in 1988, while it is substantially lower in spring, autumn and winter.

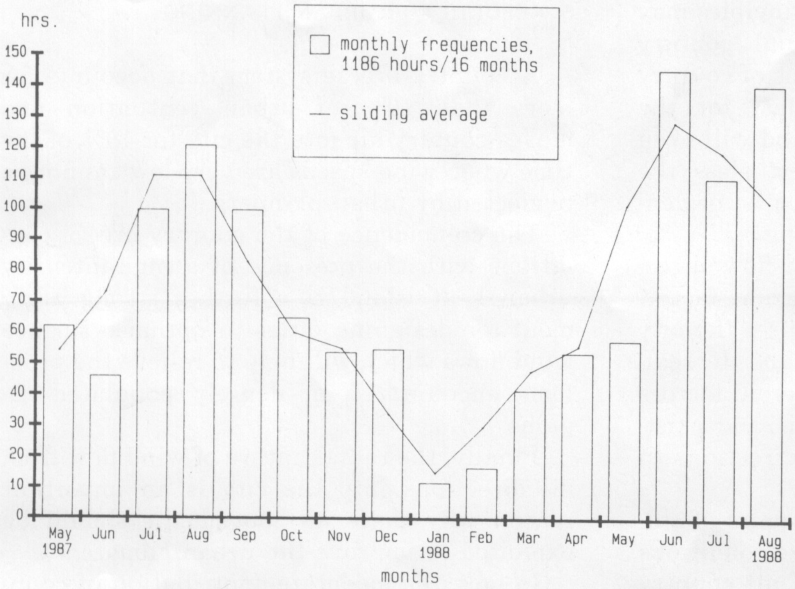

Fig. 5. Annual distribution of country breeze hours in the city of Bochum (measuring period from May 1987 to August 1988).

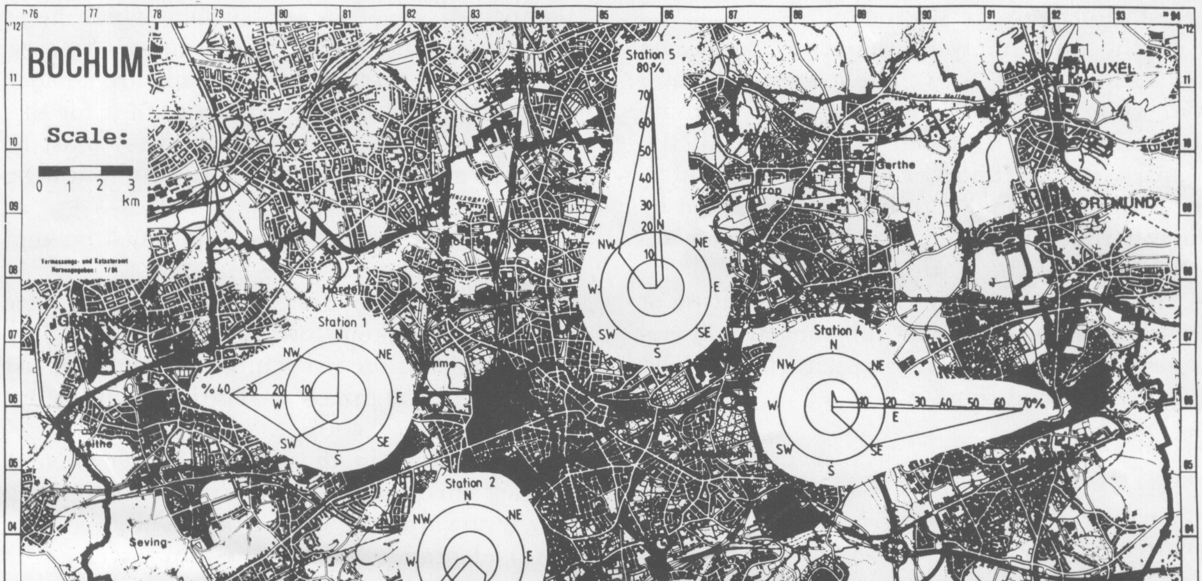

Fig. 6. Country breeze distribution in the city of Bochum (measuring period from May 1987 to August 1988).

Even though the underlying principles may be general in nature, the actual country breeze frequencies and the patterns of country breeze distribution will be typical for the Bochum local wind system only and will even vary temporally in this city. Nevertheless, the data of the Bochum study seem to be of general importance for urban planning.

The number of centripetal air-flow directions is, of course, another important factor. In theory, country breezes may enter the city from all directions at the same time. In reality, however, a multiplicity of different factors such as meteorological conditions and existing buildings will cause certain directions to prevail.

During the test period several pairs of stations often recorded country breeze conditions simultaneously (Table 2). 72% of all country breeze conditions were registered by at least two station pairs and 20% even by at least three station pairs. Simultaneity only drops to a negligible 3% and less than 1% for four and five station pairs, respectively.

In the final analysis, the study confirmed the existence of a well-defined centripetal country breeze system in the city of Bochum depicted in Fig. 6, which is based on all the country breeze hours recorded. The differences in directional stability are explained by the different surface structures in the immediate vicinity of the stations.

The study has shown that the ventilation of Bochum can be improved substantially by appropriate urban planning chiefly under low-speed wind conditions.

TABLE 2

Simultaneous registration of country breezes at several station pairs (measuring period from May 1987 to August 1988)

Number of stations pairs	Country breezes	
	Country breeze hours (h)	Part of total time (%)
At least 1	1186	100
At least 2	766	72
At least 3	234	20
At least 4	39	3
5	8	<1

5. RESULTS FOR URBAN PLANNING

A country breeze system that accounts for more than 10% of urban ventilation and moves country air into the city for 18% of the time when wind speeds are very low cannot be neglected by urban planners.

The coincidence of the country breeze conditions with the presence of a high-intensity urban heat island is a further strong argument for designing cities to optimize surface wind flows which will help to relieve the problems encountered in densely populated regions.

Finally, the radial nature of wind flow from all directions into the city is an important reason why these air movements should be exploited to improve the urban climate.

In fact, the moderate contribution of country breezes to urban ventilation highlighted by some authors is not explained by the convection–advection system itself, but by city structures. It is the responsibility of urban planners to create a city surface which helps to enhance the efficiency of country breezes. Existing town structures certainly are a major problem, and it is crucially important for this reason to maintain free spaces. They must be planned and designed to satisfy the following standards:

(a) almost straight free aisles must be kept to the centre of the city;

(b) surface roughness along these free aisles must be kept low;

(c) ventilation aisles into city centres must feature low-roughness vegetation to filter out pollution;

(d) surfaces in these areas should have a cooling effect on the ‘thin-layered’ air moving slowly towards the centre of the city;

(e) clearances to take air into the city centre should be designed to give directional stability to air flows;

(f) pollution should be minimized in the areas from which air moves to the city centre and along the ventilation aisles.

6. CONCLUSIONS

The study of the Bochum country breeze regime has shown the importance of an efficient thermal surface wind system for urban ventilation.

It is the responsibility of urban climatologists to provide the scientific data needed to improve the climate in cities, and it is the difficult task of urban planners to adapt these data efficiently for city design.

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