SPATIAL AND TEMPORAL STRUCTURES OF THE URBAN CLIMATE - A SURVEY

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ABSTRACT. In this paper the elements of the urban climate are described and discussed in an overview. After having dealt with the bioclimatical consequences of the air-hygienic problems the "heat-island" effects are investigated in view of the formation of low-lewel breezes. Furthermore some examples show possibilities to convert climatological data into planning processes.

1. INTRODUCTION

The term "town" means a highly populated area which with its rows of adjoining buildings constitutes a built-up area. A division of labour has taken place among its citizens and the town itself exercises an attraction on its surrounding countryside.

Despite the apparent socio-economic advantages rarely being realized because of the what is often a drastic deterioration in the environment, even in the last decade the development of the urbanization process has njoyed unchecked growth from the pedestrian period (up to about 1880) to the telecommunication era (since 1975) (BURDACK 1985). This applies to both the continuously increasing use of land (from about 20 m^2 per inhabitant in the 50's to 40 m^2 in the 80's, BOESLER 1987) and to the increasing urban populations worldwide.

Whereas only about 20 % of the entire world population lived in cities or towns at the beginning of the 20^{th} century we must expect a figure of 40 % at the beginning of the 21^{st} century (OKE 1986; SCHÖLLER 1983).

In contrast to the developing countries, however, the industrialized nations traditionally have a higher percentage of urban population. This share is expected to reach 80 % in the year 2000 (fig.1).

Conflicting aims result from the intense spatial entanglement of a dense urban population and the immissions into the ground air layers of agglomerations. The only solution is the ensurance of a permanent supply of fresh air and favourable human-bioclimatic conditions for the population.

It is the special function of applied urban-climatology in the fields of

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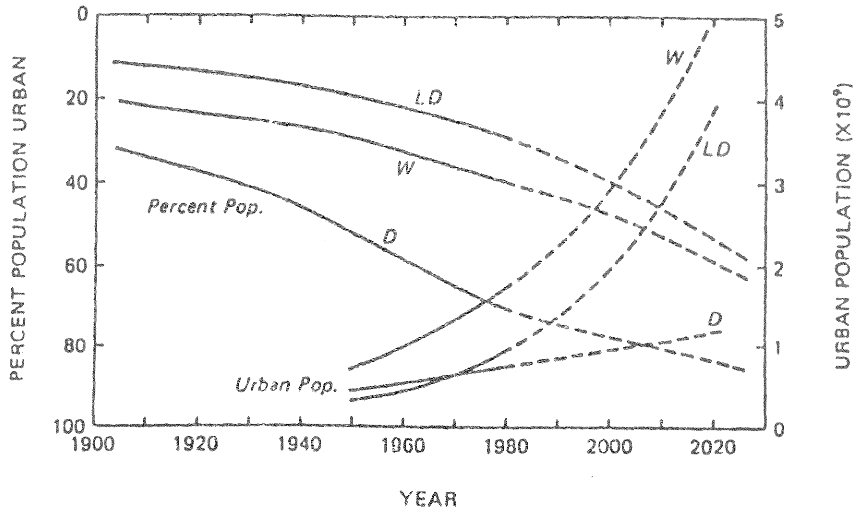


Fig.1:

LD = Africa, Asia, Latin America and Oceania
D = Europe, North America Australia, Japan and USSR

Data and projections using the United Nations sources according to SASSIN (1980) & PETERSON (1984)

Fig.1: Percentage of the population in urban areas in the Less Developed (**LD**), Developed (**D**) and total World (**W**) communities, and the number of urban inhabitants according to the same groupings.

inventory and interpretation of urban-ecological parameters, both to analyse the micro- and mesoclimatic conditions and to find answers to the questions still open in the area of town planning.

The factors which lead to the mesoclimate of our towns and cities are mainly, an increase in surface-roughness, a high amount of highly built-up areas and too few green areas. The result: In contrast to the surrounding rural areas, the ground levels of urban atmosphere show a different structure as can be shown schematically in fig.2.

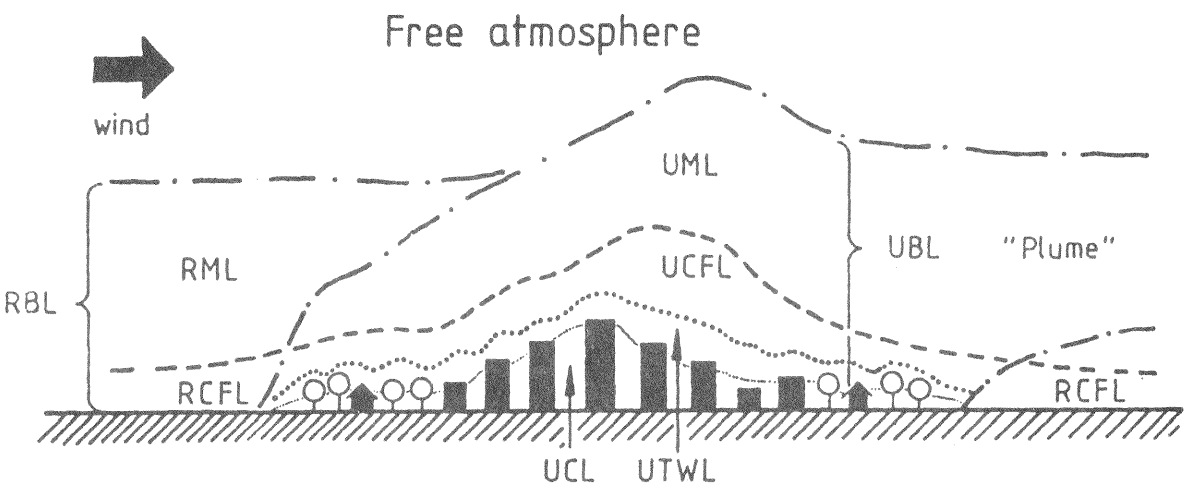


Fig.2: Modified structure of the boundary layer (after WANNER 1986)

2. THE STRUCTURE OF THE URBAN ATMOSPHERE

The Rural Boundary layer (RBL) above the flat surrounding area can be subdivided into the PRANDTL-layer, or Rural Constant Flux Layer (RCFL), and the EKMAN-layer or Rural Mixed Layer (RML).

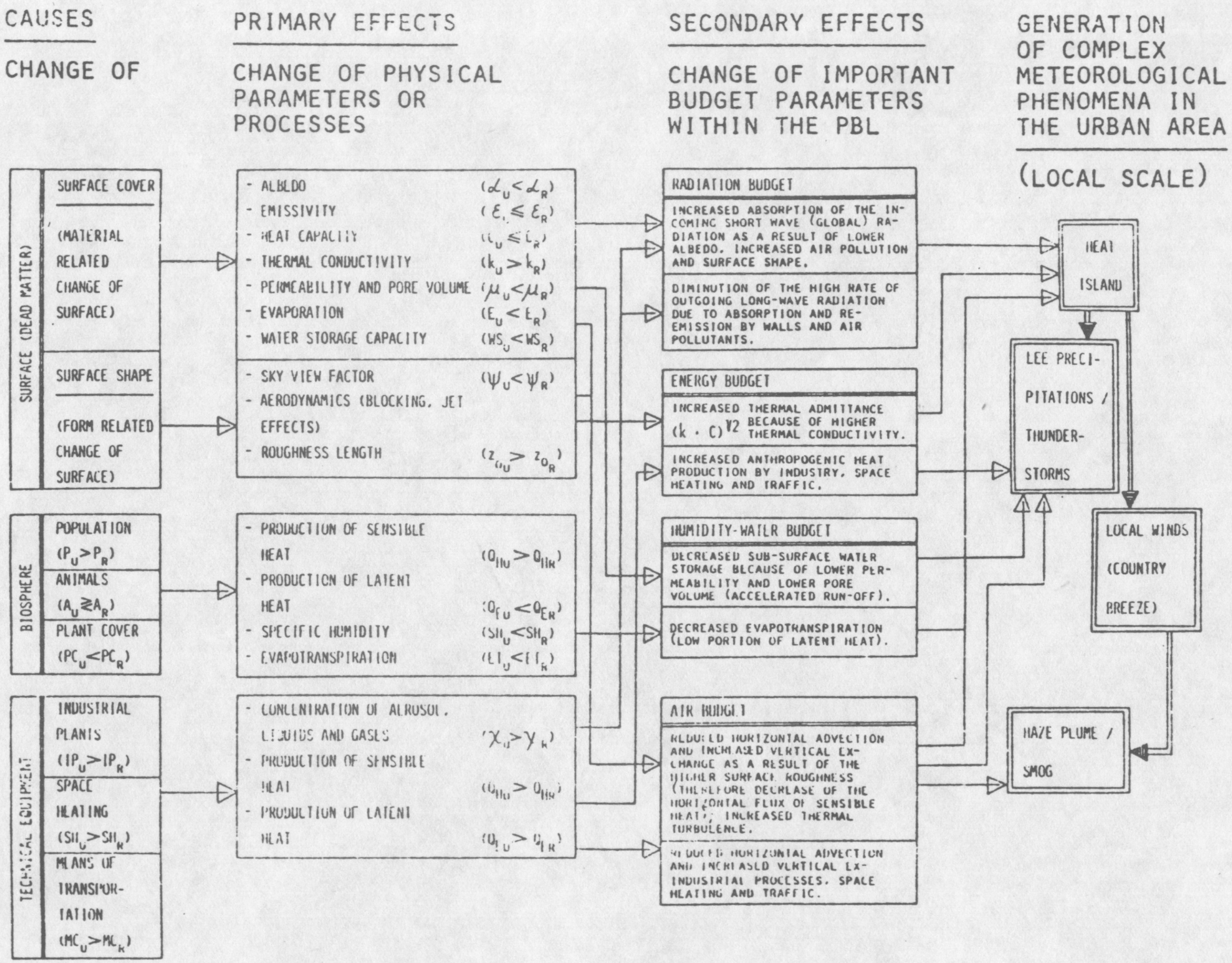
The RCFL lies like a "skin" on the ground and reaches a maximum height of 100 metres. The RML lying above this, however, reaches a height of some several hundred metres, whereby the change in wind directions increases with height as the influence of shearing-stress decreases allowing gradient power and Coriolis-acceleration to dominate. When approaching the atmospheric structure of a town one can particularly observe an increased height in the CFL. While the RML becomes an UML, the UCFL "fans out" into the UCL above the ground and into the TWL. The UCL is the "skin" that covers the built-up area, whereby the dynamic of the air-skin is uncoupled from the remaining boundary layer up to about 2/3 of the height of ground objects (e.g. buildings, trees) (WANNER 1986, p.71) i. e. the exchange processes occur in micro-scale.
As mentioned, above UCL there is a turbulent transitional layer incorporated in UCFL which in general reaches twice or three times the width of buildings (OKE 1984).
The UBL - which is situated above UCL as a meso-scalic boundary layer - is larger in the daytime (0.6 to 1.5 km) than at night (0.1 to 1.3), as radiation causes convection and thus increases the thermic turbulence (OKE 1983). However these conditions occur only during weather conditions with neutral stratification of the atmosphere. During windless weather conditions, especially on days with high amounts of radiation, different behaviour in the layers can be observed.

The vertical structure and heights of the layers shown in fig.2 are influenced by widely differing factors determined by the balance of radiation and energy.

3. PARAMETERS INFLUENCING URBAN CLIMATE

Thus, the changed characteristics of urban surface (tab.1) lead to e.g. a decrease of short-wave albedo, long-wave emissivity, volume heat, soil permeability and pore volume as well as evaporation, water storage capability and the sky view factor. Higher values (with partial restrictions) are only determined for heat conductivity and the roughness length (z_0) of the built-up area. Typical values of the roughness length of a city amount to i.e. $z_0 = 0.02 - 3.0$ m (MALBERG 1985; OKE 1973) quotes values for urban areas of z_0 equals 1 % to 10 % of the height of the building. According to BAUMGÄRTNER et al. (1977) z_0 can be determined with the approximation formula $\log z_0 = 1.03 \log h - 0.86$, whereby h equals the height of rough elements in metres.
As an example of change in the biosphere one can easily see (group 2 in tab.2) that the towns and cities have fewer plants as well as a smaller share of plant coverage, which is e. g. for downtown West- Berlin about 32 % but reaches 95 % in the outskirts of the city. Even the range of species changes in the towns and cities: the share of hemerochores rea-

ches 50 % whereas only about 30 % predominate in the countryside (SUKOPP 1983). Densely built-up areas combined with a lack of vegetation result in lower values of latent heat, specific humidity and evapotranspiration, but on the other hand also cause more sensitive heat-fluxes. The third group incorporates technical facilities that partially influence the UBL directly. In this group we mainly refer to the exhaust fumes from smoke stacks, but also to these form different types of transport and the high number of domestic heating systems.



Tab. 1: Urban climate: pattern of interactions (after WANNER 1986)

All these factors are partially responsible for strongly increased flow densities of sensitive and latent heat as well as - from the point of view of air hygiene - increased concentrations of solid, fluid and gaseous particles.
The prominent mark of urban - industrial agglomerations visible from afar are the smog covers above the municipal areas consisting of a wide spectrum of gaseous and solid particles emitted from the agglomerations. Their existence is dependent on the type, height and strength of the source as well as the photochemical changes of the pollutants during their transmission.

3.1 Air Pollution

The numerous emissions in the urban atmosphere can be classified into distinct groups of pollutants e. g. sulphur, nitrogen and halogenous compounds as well as hydrocarbons, oxidants and dusts.
As far as immissions are concerned SO_2, NO_x, O_3, CO, C_m, H_n, dust and heavy metals have - often continuously - been a matter of investigation for several years in a number of agglomerations, sometimes with a large-scale network of measuring stations.

An analysis of the groups of polluters for the Rhine-Ruhr-District with regard to the whole spectrum of emissions in the five polluted areas, shows an average of 18.8 % for domestic heating systems, 22.8 % for traffic and 58.4 % for industry and power stations (KUTTLER 1987). With these immissions, it must be said that one can observe different trends depending on the measuring station and the measuring period. The strong dependency of e.g. the ground level SO_2 concentration on the heating habits of the population, can clearly be seen in the latest data from the municipality of Stuttgart - (BAUMÜLLER & HOFFMANN 1987) and here we must remember that in the FRG, 59 % of individual heating systems are fired by heating oil or coal (SOLFIAN et al. 1987). It shows a highly significant correlation to the mean monthly temperature per day with a given variance of $r^2 = 0.98$. In West-Berlin the share of emissions from domestic heating make up 24 % while its immissions account for a share of 45 % of total pollution (HASSEMER 1983). High concentrations of immissions can be observed for a short time during prevailing windless weather conditions as the occurrences of smog in many German agglomerations showed last winter .

Even a simple analysis of the concentrations e. g. for SO_2 and NO_x, divided into inversion and non- inversion days in a town (fig.3), shows that the values for inversion days are higher than those for days without inversions by a factor of 2.1 for SO_2 and 2.2 for NO_x. The figure also shows that these conditions mainly occur during the winter-half of the year. With the help of a flow-chart similar factors of increase have also been calculated for SO_2-concentrations during low-lying inversions in West-Berlin (ground-level). The main polluter during periods with very high concentrations of pollution given here as being a low lying spatial source, is above all domestic heating (KUTZNER 1983).

In contrast to SO_2, O_3 has the highest values in summer in particulars around noon because of the dependence on different "predecessorgases" and the intensity of sunlight.

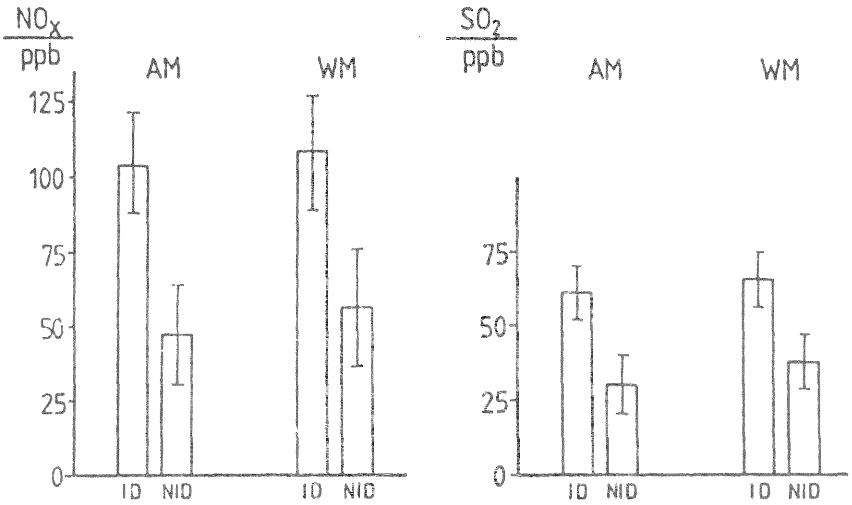


Fig.3:

Average concentration of SO_2 and NO_x of days with (ID) and without (NID) temperature inversion

(height = 700 m above surface; high polluted city in the Rhine-Ruhr-Area, 1982-1985)

(**AM** = annual mean; **WM** = winter mean)

In addition, higher O_3 concentrations with less significant day-time trends can be observed in clean-air areas where pollution is mainly caused by long-distance transport (PFEFFER 1985).

Besides the contingencies influenced meteorologically, certain other influencing factors not caused by meteorological exchange conditions can also be proven for some highly polluted urban areas, such as, weekly trends in the concentration of immissions traceable purely to the consumption of particular types of fuel.

Fig.4 shows what is in part distinct differences between weekdays (Monday to Friday) and weekend values for immensely polluted measuring-stations in the Rhine-Ruhr-Area. The greatest differences have been found for NO which shows values as being 55 % higher on weekdays than at weekends, followed by dust at 14 % and SO_2 at 12 %. Increased values on weekdays measured at a station near the centre have also been proven for Munich. The findings were an additional 46 % for NO and 22 % for SO_2 (NOACK et al. 1986).

The trends for O_3-concentrations in the Rhine-Ruhr-Area, however, are quite the reverse. The weekend-values were 19 % higher than during the week.

If the differences seen between weekdays and weekends can be explained with the higher energy consumption and increased use of private vehicles typical for weekdays, the higher O_3-concentrations on weekends are at first sight, all the more surprising.

This could be linked to the fact that the ground-level atmosphere contains less NO_x on Saturdays and Sundays than on weekdays, so that less O_3 is reduced. However, this is only plausible as the process of synthesis and degradation is very complex (BRUCKMANN et al. 1980).

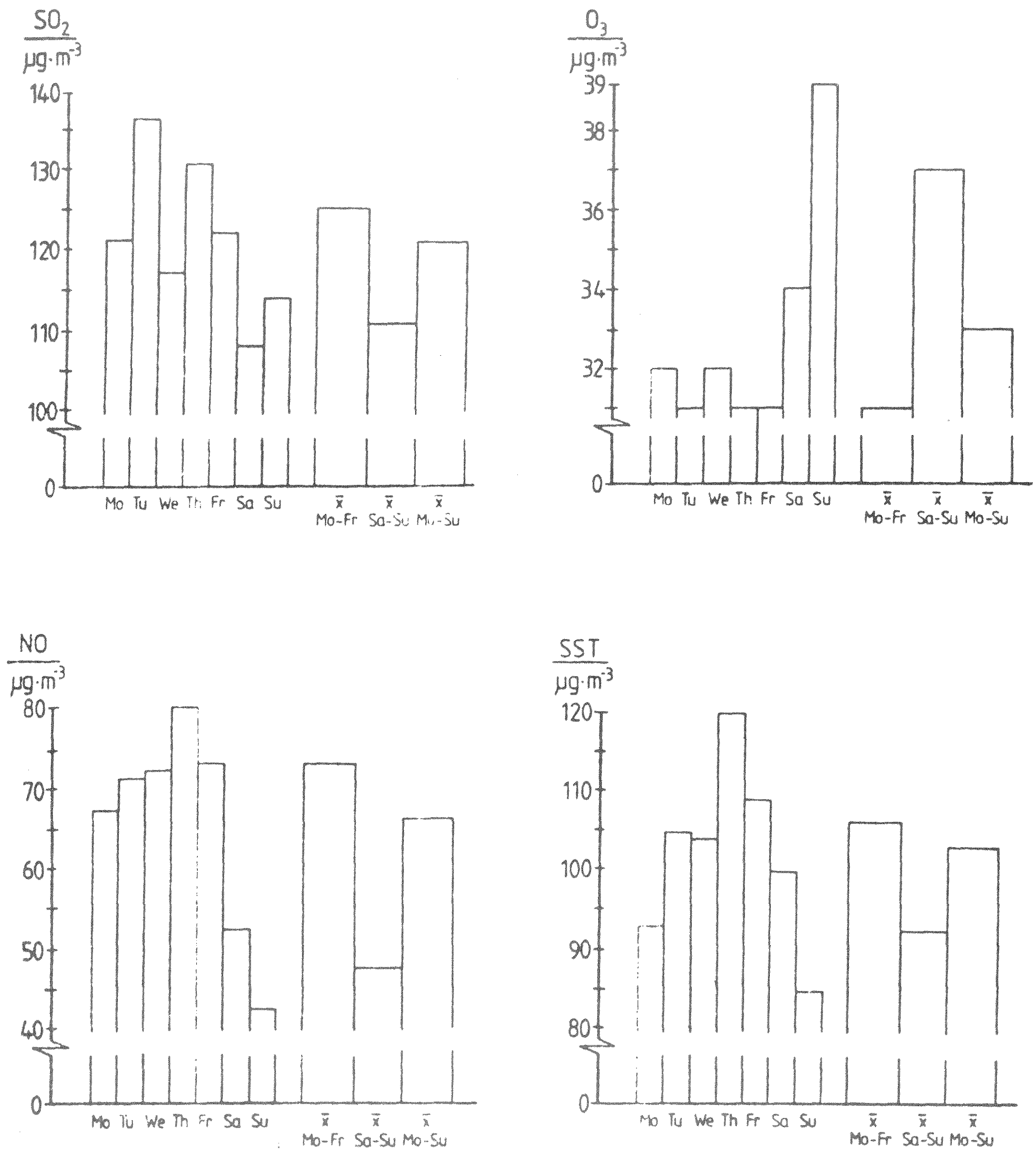


Fig.4: Average daily concentration of air pollutants at a high polluted station in the Rhine-Ruhr-Area (measuring period: Jan.-Dec. 1982) (data after PFEFFER et al. 1985)

Long-term measurements in polluted areas taken over a number of years show different trends in some pollutants: while the CO-values have decreased very slowly (DEIMEL 1982), the NO_x-values have been increasing considerably, particularly since the beginning of the 80's. Considerable decreases in concentrations can be observed in SO_2, SST, B(a)P in dust, (HEINRICH 1982) as well as in lead, this being a direct result of the

Petrol Lead Acts of 1972 and 1976. For example a reduction of more than 80 % in the SO_2-concentration during the period of 1966 to 1984 was shown in Munich (NOACK et al. 1986).

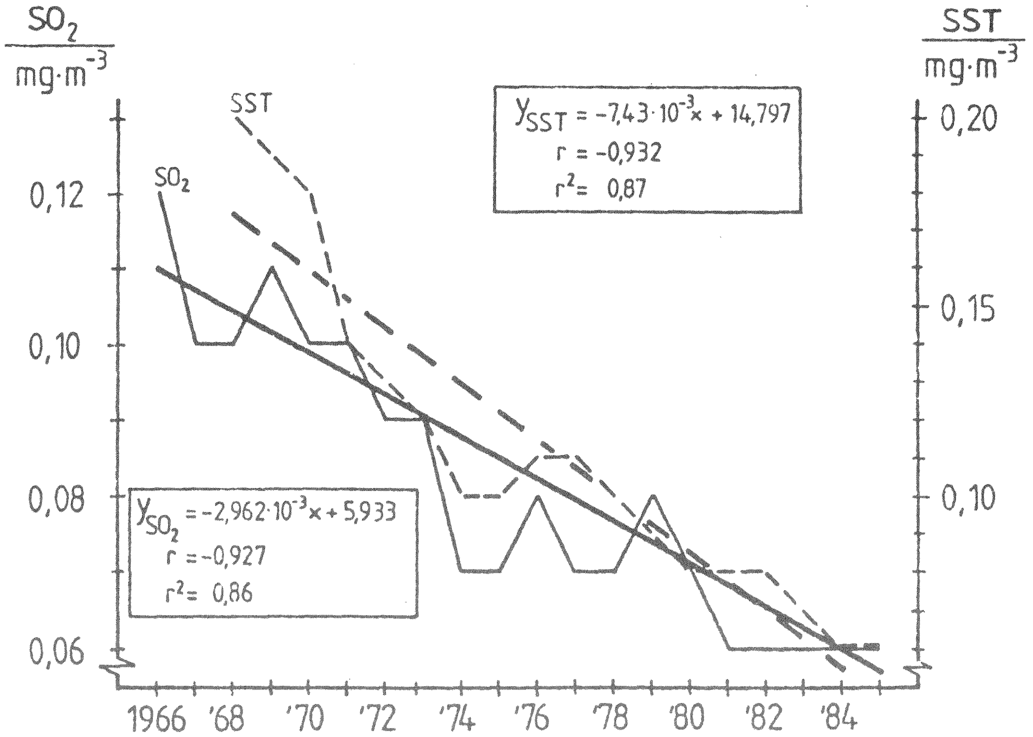


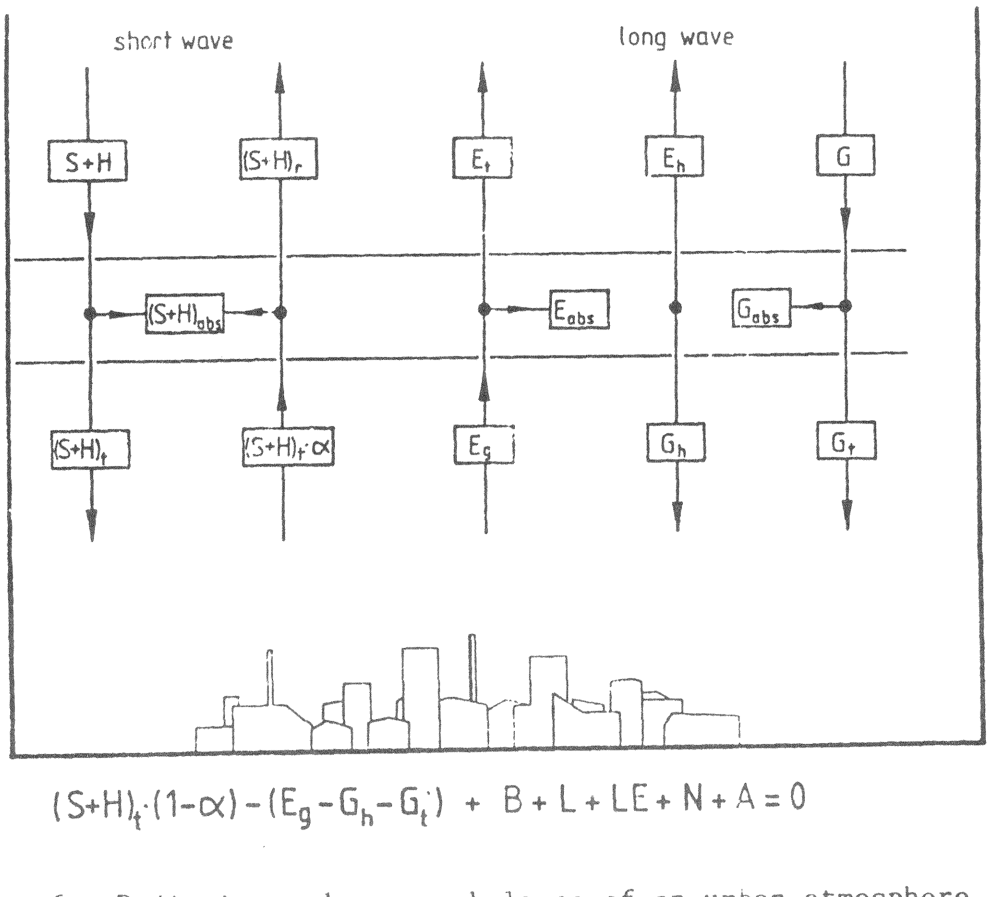
Fig.5: Yearly mean of SO_2- and **dust**- concentration (SST) in the Rhine-Ruhr-Area (data after BUCK et al. 1982 and LIS, Essen)

Fig.5 contains two examples from the Rhine-Ruhr-Area, showing a decrease of 50 % for SO_2 and 78 % for dust in the period between 1966 to 1984. For SO_2 - of which more than 90 % is produced by domestic heating, industry and power stations - it became obvious that the decreases occur both in summer and in winter, but with a considerably higher decrease during the cold season. As there is no demand for domestic heating in summer, industry and power stations are the only polluters of ground-level atmosphere in this period. In winter, however some 50 % of SO_2 emissions can be ascribed to domestic sources and the remainder to industrial emissions. It is therefore reasonable to assume that the decrease is due to a reduction in both industrial and domestic emissions. This marked decrease in winter is also a result of the policy of replacing short smoke-stacks, still widespread in the 60's, with higher ones. This enabled the pollutants to spread themselves above the relatively low upper boundary of the exchange layer in winter, about 400 to 600 metres above sea-level, thus removing them from the local ground-level atmosphere (BUCK et al. 1982; KUTTLER 1979).

4. BALANCE OF RADIATION AND ENERGY

The input and output of the urban fluxes of radiation and energy have been considerably changed by the aerosols and gases released into the urban atmosphere, as well as by the structure of the built-up area on the surface (fig.6). The smaller share of global radiation (S+H) supplied to the ecosystem city is absorbed or reflected by gases and particles in the smog-cover. In the Ruhr-area, using a sunshine-autographer, we calculated an average loss in the hours of sunshine of 0.3 h/d (KUTTLER 1985 a). A reduction of global and ultraviolet rays in a town are therefore caused by the urban smog cover which incidently reached 10 to 20 % in Munich (NOACK et al. 1986). Most of the radiation on the other hand penetrates to the urban surface resulting in absorption ($(S+H)_{abs}$) and - depending on the different materials on the surface - a lower or higher rate of reflection $(S+H)_t$. Using recent readings a value of urban albedo of 14 % can be determined (NOACK et al. 1986).

The long-wave radiation from the surface (E_g) is dependent on the surface temperature and the constants of material emissions. It is partly absorbed (E_{abs}) and also re-emitted by the smog layer. The long-wave counter-radiation is transmitted (G_t) and partly absorbed (G_{abs}) by the smog cover and again re-emitted onto the urban surface as well as into the hemisphere above the smog cover.



$$(S+H)_t\cdot(1-\alpha)-(E_g-G_h-G_t) + B+L+LE+N+A=0$$

Fig.6: Radiation and energy balance of an urban atmosphere

The thermic processes engineered by global radiation cause the building structures to heat up - and here the buildings can increase - the area available for energy transfer by factor 6 (ERIKSEN 1975). They also cause the flux of sensible (L) and latent heat (LE) as long as sufficient water is available for evaporation.
The artificially produced "anthropogeneous" energy (A) is released near to the ground into the UCL or by smoke stacks directly into the UBL and remains in the urban smog cover.
The "anthropogeneous heat production" is to be seen as a form of energy that does not result from the natural energy surplus, but, for example from the flux of energy through badly insulated houses and industrial plants or heat emissions from vehicle-motors or exhaust fumes of all types as well as heat deriving from the metabolism of living organisms (HÖPPE 1984). This artificially produced heat becomes particularly apparent on cold winter days, as KERSCHGENS & DRAUSCHKE (1986) were able to show using Bonn as an example. Their analyses were based on the urban energy consumption of oil and electric energy, traffic censuses and estimated metabolic energy production based on the distribution of the population in the town. It was shown that with regard to the area of the town, (fig.7) the amount of energy released metabolically did not reach 5 Wm^{-2}. This value is supported by Japanese findings (FUKUOKA 1983). Slightly higher values resulted from traffic with maximum values in rush-hours of up to 10 Wm^{-2}. Estimated waste heat from vehicles in the

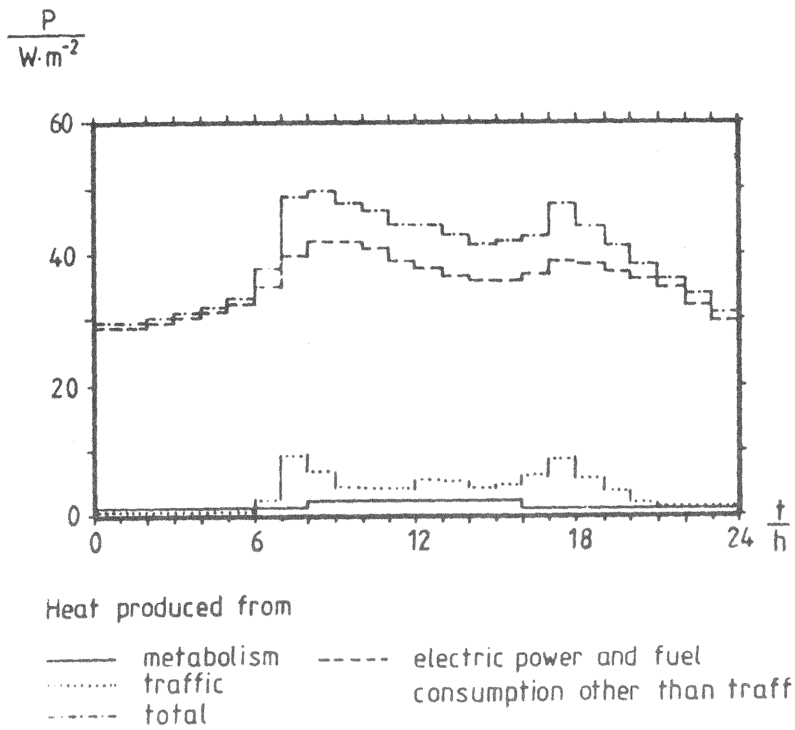


Fig.7:

Hourly mean values of the anthropogenic heat release of the urban area (Bonn) in February 1983

(after KERSCHGENS & DRAUSCHKE 1986)

town of Bochum gave an annual mean value of about 5 Wm^{-2}, corresponding roughly with the total global radiation of 4.4 % (KUTTLER 1985 b).
The decisive elements in "anthropogeneous heat release" are of course those flows of energy related to the consumption of oil, coal and

electricity which, in proportion to consumer demand - for example in Bonn, amount to 30 Wm^{-2} at night and 40 Wm^{-2} during the day. A rough estimate for the city of Essen carried out recently with the help of a heat requirements forecast, obtained a similar result of 40 Wm^{-2} as an annual mean value.
The amounts of anthropogeneous heat production calculated for some municipalities in different climatic zones partially showed differing values: a factor of between 0.2 and 0.4 times the balance of radiation for cities like Berlin or Hamburg; for Moscow, during the cold season however 3 times the total balance of radiation (compare classification in KUTTLER 1985 b).
Further factors which additionally increase the balance of energy of urban ecosystems, is the lack of vegetation and the high degree of built-up areas which lead to accelerated precipitation into sewerage and thus reduced evaporation. The energy that is not used for evapotranspiration is therefore available for heating the air. This can also be seen in the BOWEN-ratio calculated for towns which are, in general higher than the surrounding countryside.
In contrast to natural surfaces like grassland and forests (fig.8) which show negative values in the early morning and the evening (as (H) becomes positive) ß remains positive in the city (as (H) and (LE) are negative) and reach values of more than 1.0 around noon. This means that most of the energy reaches the atmosphere via the sensitive heat flux. The urban ß-values in the morning and the evening of less than 1.0 prove that "the city is not the desert for which it is sometimes held". (GARSTANG et al. 1975, p.155).

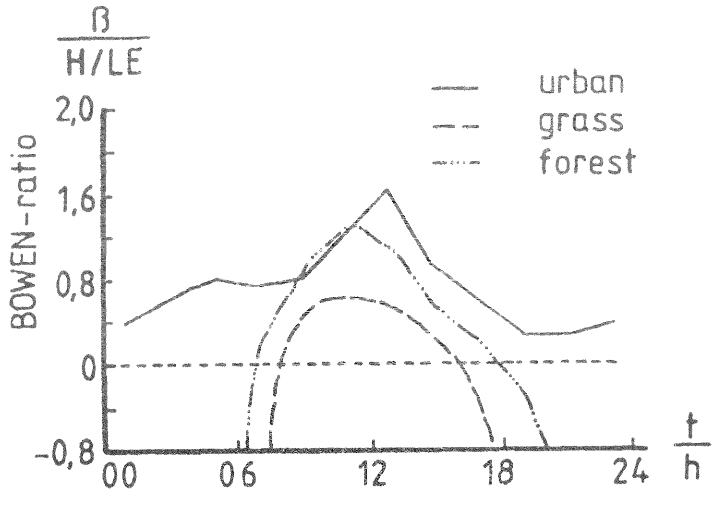


Fig.8:

Diurnal variation of the BOWEN-ratio over various surfaces.

(after OKE et al. 1972; from GARSTANG et al. 1975)

The dependence of the BOWEN-ratio on the share of green-areas (G) (fig.9) shows that the increase of (G) to 100 % ß at noon only amounts to about 0.8. On the other hand ß increases when (G) decreases. If the share of green-area is lower than 25 %, ß exceeds 1.0 at noon.

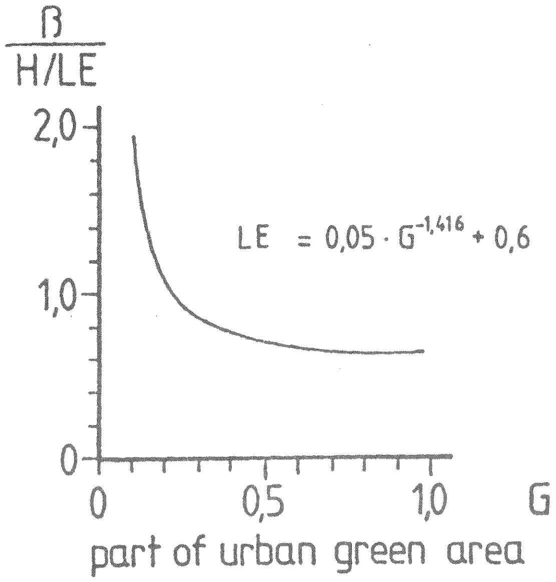


Fig.9:

Dependency of the BOWEN-ratio (ß) on the part of urban green area (G) (high pressure area, summer, at noon)

(after KERSCHGENS & HACKER 1985, from NOACK et al. 1986)

5. THE URBAN EXCESS HEATING

The following factors can be summarized as being the causes of excess heating in urban areas (tab.2):

Altered Energy Balance terms in the urban Canopy and the Boundary layer	Features of urbanization underlying Energy Balance changes
1. Increased absorption of short-wave radiation	Increased surface area multiple reflection, air pollution
2. Increased long-wave radiation from the sky	Air pollution
3. Decreased long-wave radiation loss	Reduction of sky view factor
4. Anthropogenic heat source	Building, traffic, chimney and stack heat losses
5. Increased sensible heat input and storage	Heat flux from Canopy layer, roof, construction materials and turbulent entrainment
6. Decreased evapotranspiration	Increased "waterproofing"
7. Decreased total turbulent heat transport	Reduction of windspeed

Tab.2: Suggested "causes" of the urban heat island (not rank ordered) (from OKE 1982, shortened)

These result in differences between heating and cooling rates of air temperature for town and countryside, as shown in the seasonal trend in fig.10. The heating and cooling rate at the rural station is much higher throughout the whole year than in the city. At sunrise there is a relatively rapid warming up in the rural environment (in summer: 3.5 K/h; in winter: 1.5 K/h) as the heat conductivities of the rural surfaces are smaller than those of urban surfaces. At sunset there is a relatively rapid cooling-down (in summer: -3.5 K/h; in winter: -1.2 K/h) as the surface experiences a net radiative energy drain which draws heat from the shallow layer of stable air directly above it. While the surface temperature drops and the rate of radiative emission decreases, the cooling rate also declines as the night progresses. As a result rural air temperatures at night exhibit a decay curve until just after sunrise when the pattern is abruptly interrupted by warming up.

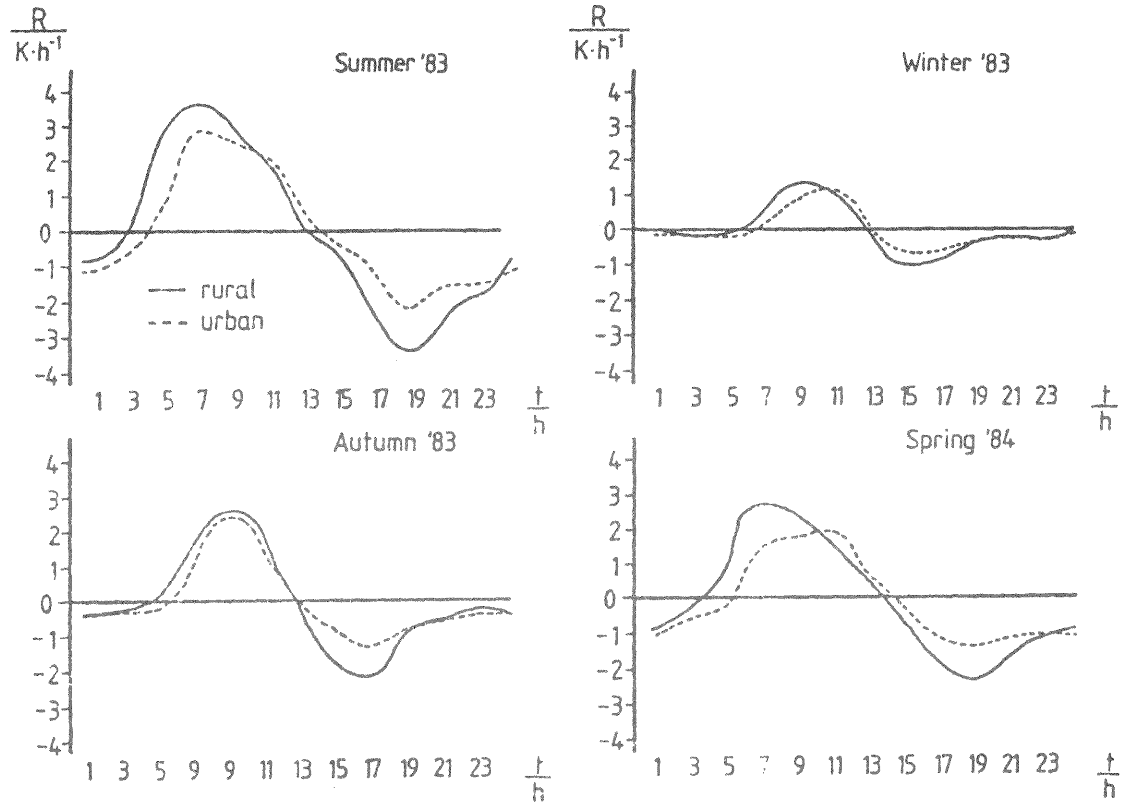


Fig.10: Heating and cooling rates (**R**) for different seasons in the city (Bochum) and rural surroundings

Fig.11 shows a varied image of the daily and annual trends of the intensity of the "heat island" in a mid-latitude town. It shows the mean hourly differences in air temperature between an urban and rural station. According to this figure, during the daytime, street canyons only experience a slight difference to the rural environment. The reason for this is that the increased radiation at noon causes a convective exchange. Further causes would be the shadows cast by buildings and the height of roof-top levels.

Differences in air temperature between urban and rural environments arise through a prevailing lack of cloud so that high radiation values from the surface can be registered as, for example for the months of July and August between 9 p.m. and 4 a.m..
Consequently, urban excess heating is mainly a night-time phenomenon. According to measurements taken by MIESS (1974) it is also dependent on the fact that the exchange values at night in the lowest layer above the surface decline considerably i.e. from 8 g cm^{-1} s^{-1} to 1 g cm^{-1} s^{-1} as compared to those during the day. Thus, only a reduced amount of the heat stored in buildings can be transported. The result: higher air temperatures than in the rural surroundings. On the basis of an analysis done in Bochum we were able to discover that the downtown area is, in about 80 % of all hours in the year up to 3.5 K, warmer. For the remaining 20 % it has the same temperature as the rural environment or is up to 1.2 K cooler, especially in the period between mid-February and mid-September, i.e. mainly in the summer half between 7 a.m. and 5 p.m.

The spatial distribution of urban excess heating is closely related to the type and structure of building facilities, as has frequently been pointed out by WEISCHET (1979, 1982; WEISCHET et al. 1977) and which is proven by numerous measurements in urban climate. For further literature on this phenomenon, please refer to KUTTLER & SCHREIBER (1984).

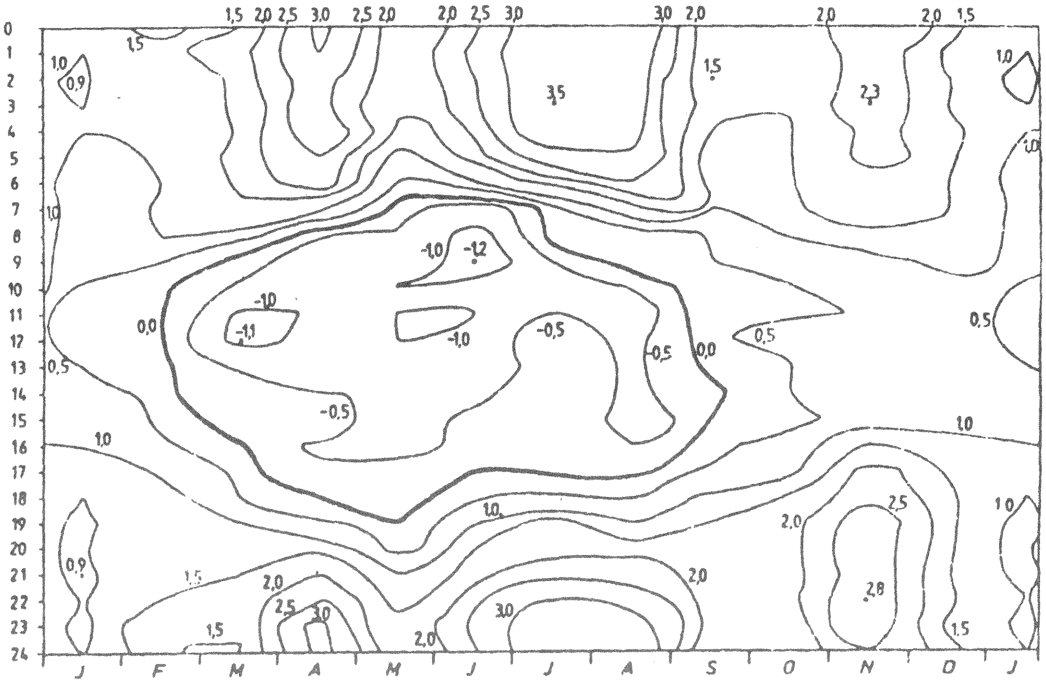


Fig.11: Diurnal and annual variation of the heat island intensity ($\Delta t = t_u - t_r$)(Bochum 1984) (KUTTLER 1985)

Windless or low wind velocities and a stable stratification of layers in urban ground-level atmosphere promote the generation of the urban "heat island". Measurements taken in Vienna (BÖHM & GABL 1978) show for example (fig.12), the close connection between the vertical distribution of wind velocities above a city and the generation of the urban "heat island".

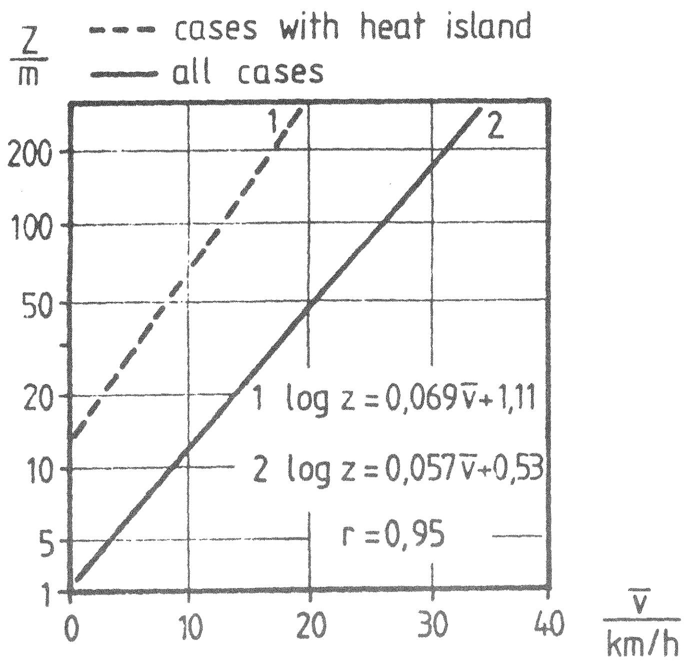


Fig.12:

Vertical profile of wind speed over the city of Vienna

(after BÖHM & GABL 1978)

As you can see in fig.13 under stable vertical gradients a "heat island" is formed in the UBL, (here I refer you to LUDWIG 1970 and KRAUS 1979), whereas with neutral or unstable strata, the town is cooler than the surrounding countryside.

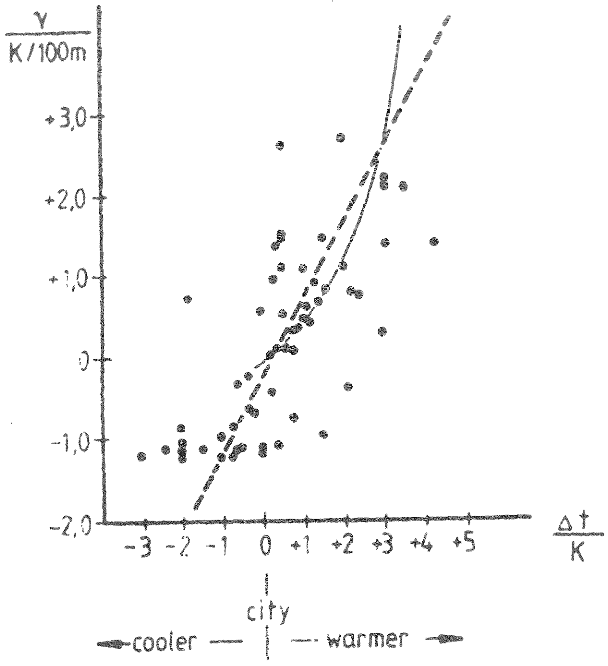


Fig.13:

Relations between temperature gradient and heat island intensity

(after AHRENS 1981)

- - = regression curve
— = theoretical curve

(after MUNN 1973)

There have been some attempts made to find whether the intensity of the "heat island" bears any relationship to the size of a city and its population.
FUKUOKA (1983), YOSHINO & KAI (1973) and OKE (1973) were able to show that the intensity of the "heat island" could be determined by the size of the population. YAMASHITA (1980) was able to prove that the intensity of the "heat island" is dependent of the height of the buildings. With reference to OKE & HANNELL (1970) KRAUS showed a relationship between the generation of a heat island and the critical wind velocity on the logarithm of the number of inhabitants (fig.14).

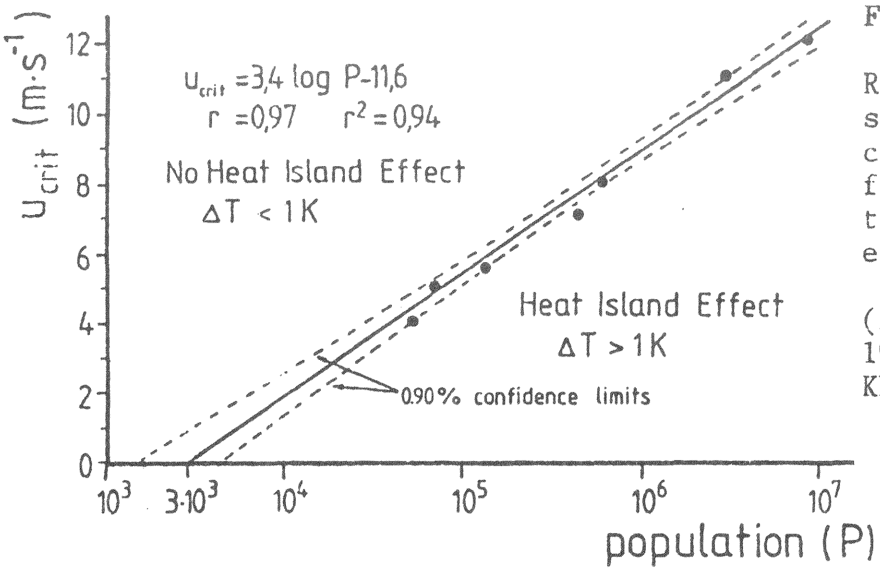


Fig.14:

Relation between city size (P) and the critical wind speed for elimination of the urban heat island effect (u_{crit})

(from OKE & HANNELL 1970; modified by KRAUS 1979)

Apart from the formation of heat islands in the horizontal plane a three dimensional structure can also be observed, only typical, however, during weather conditions with high amounts of radiation. As you can see from fig.15 with a fall in the different temperatures in town and surrounding countryside, the urban "heat island" reaches a height of 200 m - in this example at night. Above this level which is called "crossover" it is cooler above the city than above the rural environment.

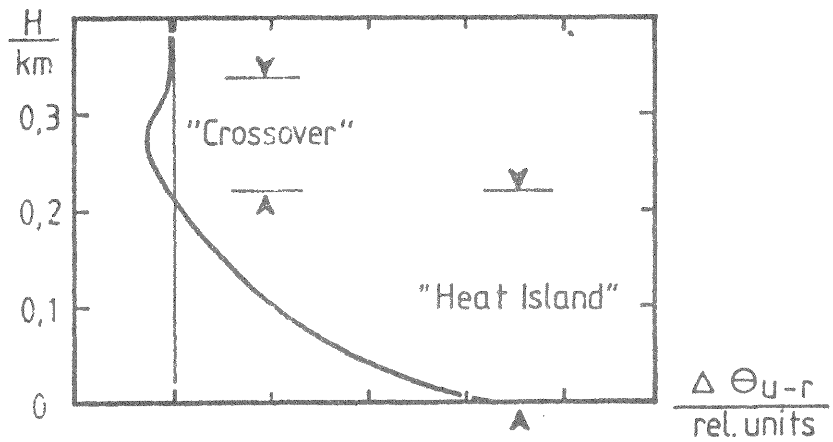


Fig.15:

Crossover and resulting vertical profil of heat island intensity in the city centre at night

(after OKE 1982)

According to investigations made by DUCKWORTH & SANDBERG (1954), and often proved on several later occasions (BRÜNDL et al. 1986; THOMMES 1986; DELAGE & TAYLOR 1970) the following reasons can be given for the formation of a "crossover":

"The intense surface inversion (in the rural area) will cause some subsidence and consequently some adiabatic warming in the layer just above the inversion. In the city the formation of a pollutant layer is somewhat lifted by the low-level instability. This layer can cause heat loss by outgoing radiation and hence cool below the temperature prevalent at the same height in the cleaner rural air column" (LANDSBERG 1981, p.109).

This effect, however, does not influence the formation of the "crossover" at night significantly. Another possibility under discussion is that due to the stronger convection above the town, a large scale vertical exchange takes place which could result in lower temperatures at higher altitudes.

As the infra-red pictures show, during the daytime the convection above urban structures is caused mainly by the outgoing radiation from hot roofs, which can easily be proved by SODAR-measurements.

Based on 10 minutes averages, and using the city of Essen as an example, fig.16 shows an increase in the vertical wind velocities of more than $u = 0.75\ ms^{-1}$ above a height of 100 metres.

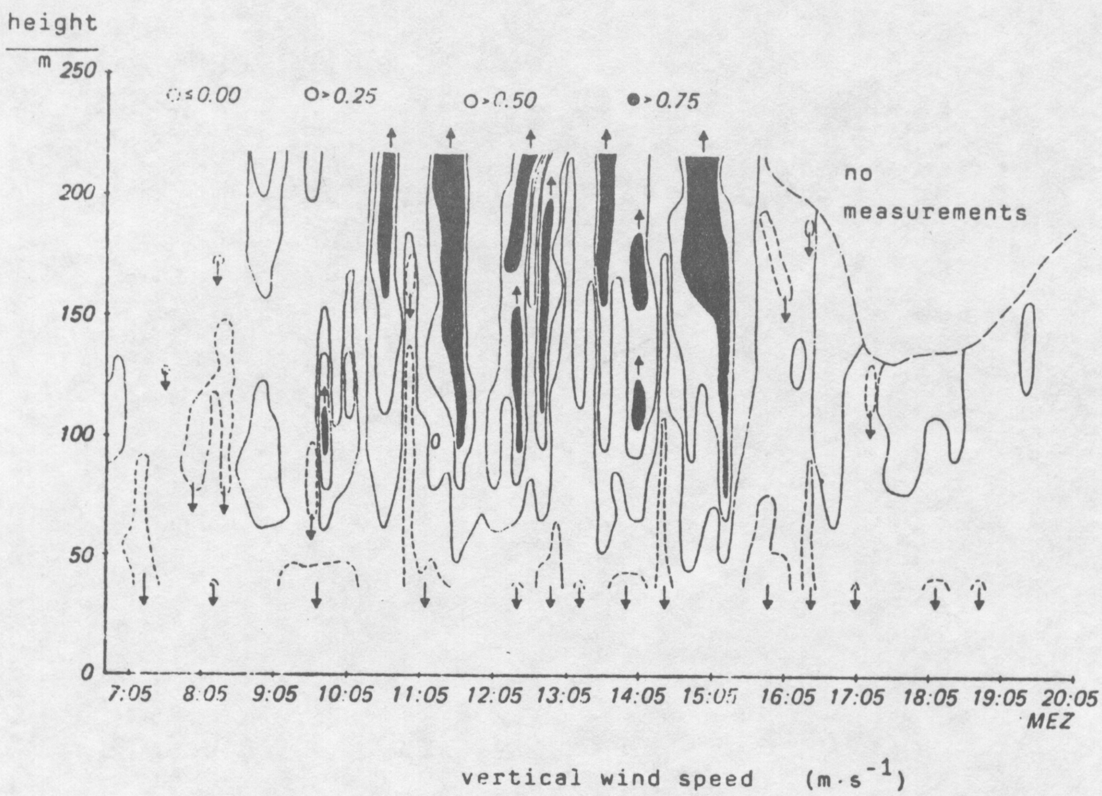


Fig.16: Vertical wind speed over the city of Essen, 27.09.1983 (after BECKRÖGE & FRANK 1986)

Using mesurements taken at the same time, the horizontal velocities above the heated city were, in part, shown to exceed those of the rural surroundings because of higher impulse exchanges caused by the higher temperatures. The exchange of air masses during low-gradient weather conditions with high amounts of radiation is only enforced by the thermic imbalance.
The resulting intermittent advection which is near to the surface and directed at a city is usually known as "low level breeze" or rural wind, and has mean velocities of only $u = 2\ ms^{-1}$ (KIESE & OTTO 1986).
On the basis of measurements taken in Dortmund, at set times during the day, the frequency of rural winds reached their maximum around 5 a.m. and minimum around noon (fig.17).

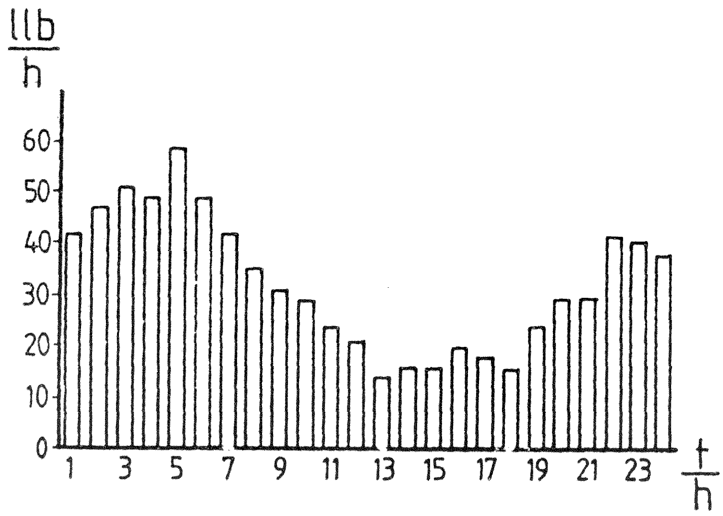


Fig.17:

Hourly distribution of low-level-breezes (Jan.-Dec. 1985)

(after KIESE & OTTO 1986)

These values have - together with the differences calculated in air temperatures between city and the rural environments -subsequently become subject to a regressional analysis (fig.18). This shows that an increase in the regression line is expected, i.e. an increase in time with rural wind, and an intensified excess heating of the city. It also seems that with corresponding intensity of the urban "heat island", the convergent winds seem to be dependent on the time of day. The resulting number of hours with rural wind was 30 hours for the 9 p.m. measurement, but 60 hours for that at 5 a.m.. The reason for this may be found in the turbulence. With stable strata there might be a separation from the superior wind system which, however, does not occur during an unstable arrangement of layers. While the exchange conditions may be characterized positively in the evenings of days with high amounts of radiation, the urban atmosphere changes to a stable arrangement at around midnight at the latest.
It must be pointed out that in general the hours of rural winds are above the regressional line in the early morning and before noon, while fewer hours of rural wind can be observed in the afternoon despite the same amount of excess heat. The occurrence and intensity of rural wind

is bound to a certain pattern of ventilation which supplies the city with fresh air, but only then, when the fresh air from the city's surroundings is not yet polluted.

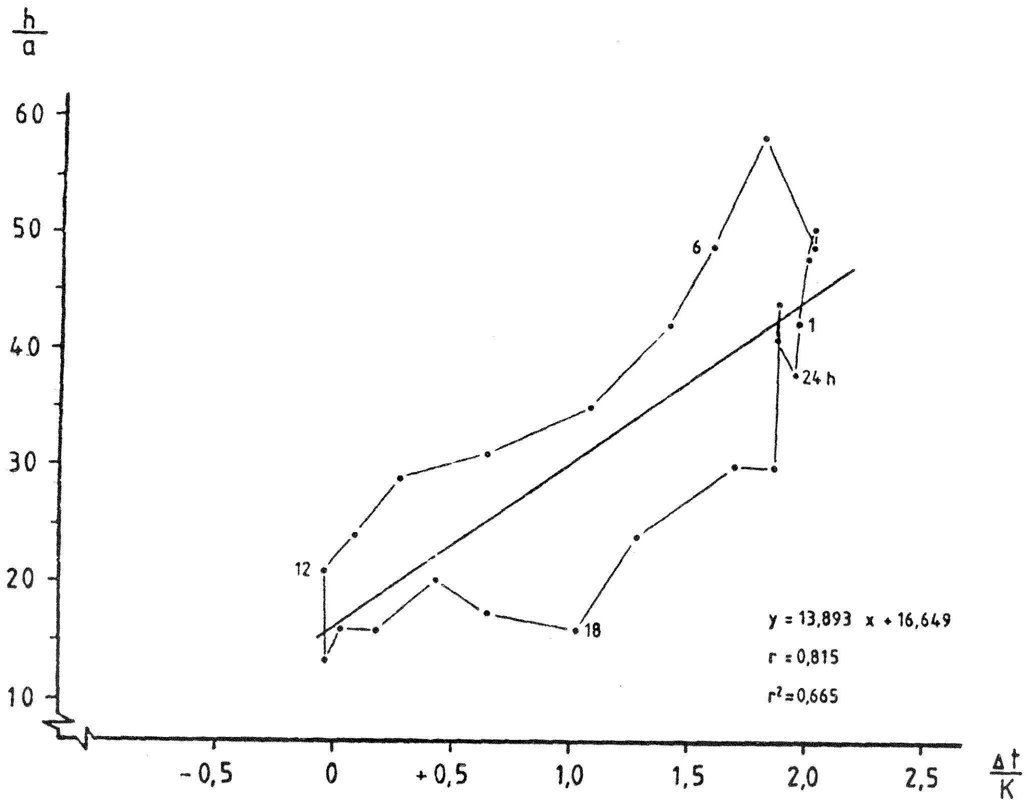


Fig.18: Dependency of low-level breezes hours on the heat island intensity; measuring period Jan.-Dec. 1985 (city of Dortmund, Rhine-Ruhr-Area)

VENT-SCHMIDT (1985) pointed out the difficulties of an evaluation analysis for cold-air flux.
Quantitative results of the potential cooling rate of an urban building structure which is cooled down by the cooler air from the surroundings, were presented by MIESS (1974).
Furthermore he was also able to differenciate between the dependence of these data on the intensity of the "heat island" and the velocity of the cool-airflux.

6. EVALUATION OF THE URBAN CLIMATE

Of the three elements in bio-climatology, actinic, air-hygienic and thermic complex of efficiency, the thermic and air-hygienic components, enjoy relatively high importance.

Registering and evaluating the air-hygienic situation involves several difficulties. It is, in fact, extremely difficult to talk about air hygiene figures on a small- scale with our current network of measurement based on the continuous or non-continuous registration of data. Mobile registering systems (i.e.: measuring vans) are a limited help, but have the disadvantage that concentrations of pollutants can only be measured periodically, one after the other.

Thus the simultaneousness of measurement important to interpret the findings is not achieved.

Another important aspect is at what height above ground level the measurement is taken. Because of the very strong horizontal and vertical variability of pollution in urban areas it is necessary to establish measuring levels above the ground, e.g. 0.5 m (height of a small child) up to 2 m (height of adults). This is also a requirement most difficult to fulfill today. A further problem springs from the orientation of measured data to fixed threshold values (i.e. IW 1 and IW 2). These values refer to the physical condition of an average group of human beings. They can therefore not be applied to people who are physically worse-off.

With increased air-hygienic pollution it is plausible to draw conclusions relating the influence of air pollution to potential human illnesses. However this is difficult to prove as being the only cause, as the time-factor also plays an important role when taking in toxic substances carried in the air (e.g. EINBRODT et al.1982). It is interesting to note that meteorological and medical science are working in close co-operation to examine and analyse the possible influences of air-hygienic components in urban areas.

For further information on this, I refer you to the literature available.

In the work carried out in the field of urban climatology hardly any characteristic values for the thermic influences based on the stationary effect of the climatic parameters have been used. In this area, the following standards are frequently used in measuring: the equivalent temperature, the effective temperature and the physiologically equivalent temperature based on GAGGE (1980). These characteristic values are widely used, as the essential meteorological basic values only have limited complexity and can thus be used by people outside the field of climatology more easily.

Since using these values, the bio-climatical patterns for human beings which have developed (FANGER 1972, PMV-value; JENDRITZKY et al. 1979; HÖPPE 1986, MEMI) have made it possible to make essentially differentiated statements on the basis of complex basic values. These model calculations are of course based on stationary parameters of the climate and the human body.

Because of the diversity of micro-climates (BURT et al. 1982) - which have e.g. certain influences on pedestrians in street canyons (i.e.

differing conditions of radiation because of differing heights of buildings and possible shadows from tree-tops), it is impossible even with these patterns, to draw any valid conclusions about the effects on pedestrians in permanently changing micro-climate conditions. The application of a pattern which also considers mobile basic values is thus an important, and necessary developement. The mobile Munich pattern of energy balance (IMEM) developed by HÖPPE (1986) has clear advantages in this context as was proved by comparative measurements and calculations. However - and this must be added with reservations - this model is only able to help drawing any valid conclusions about individuals. To solve practical problems, which are frequently concerned with making statements about the inhabitants of a municipal district, and consequently a collective statement, it is better to use the models given by FANGER (1972) and JENDRITZKY et al. (1979).

7. URBAN CLIMATOLOGY ORIENTATED TO PLANNING

If one reviews the urban-climatological history of research, three fields of investigation marking its development spring to mind. Starting with the works of SCHMIDT, HORWARD, RENOU, PEPPLER and KRATZER (all quoted in LANDSBERG 1981) the differences in temperatures between town or city and the surrounding areas always stood in the fore-front of their investigations. The results were determined on the basis of comparative stations in- and outside of a city. Mobile measurements had already been taken in early years (e.g. SCHMIDT in Vienna (1930). The purpose was to get away from the restricting results given by selective determination of single climatic parameters and to move towards spatial and representative findings.
In the period following, scientists turned to spatial, three-dimensional examinations in order to study the exchange conditions between city and rural surroundings and thereby obtained a clearer picture of the dynamics of ventilation systems for different weather conditions. In addition to the purely meteorological work carried out since about 1970 (BRÜNDL et al. 1986), air-hygienic components have been taken into consideration more and more. Since the beginning of the 80's this development has led to the utilization of the wind tunnel for the simulation of spreading processes in urban areas as well as to an intensified inclusion of the numerical simulation of mesoclimatically relevant parameters - or small spatial planning, in particular the well-known microscale pattern called MUKLIMO, which can simulate air flows above block-shaped structures (BECKRÖGE 1987, OKE 1982, SIEVERS et al. 1987).
The efforts made in research in the field of applied "reality" must finally result in a spatial description of the area examined (which must be as complete as possible). However, there are, and have always been problems in transposing the data one has ascertained from single measurements onto the total area. Here a useful method is to group all those areas with the same utilization and surface structure into so-called "climatic topes" (climatopes) (HORBERT et al. 1986). Climatopes, plots showing "uniform, long-term features of land and micro-climate even during different weather conditions" (LESER 1978, p.139), are mapped as

synthetic and functional maps of the area's climate (HABERL & STOCK 1983). In addition to the description of the spatial "distribution" of the climatic parameters relevant to the urban area and its causes, these maps also incorporate a differentiated list of the various climatic effects as was required by HORBERT et al.(1985).
The necessary data is based on the establishment of special measuring networks, the analysis of blocks of buildings with similar structures and the incorporation of infra-red thermal pictures (STOCK & LEHNER 1986).
With these aids, it must be remembered that only temperatures equivalent to radiation are given. Before they can be used for further utilization, these temperature values, however, have to be corrected - as had not been done before and which was quite rightly criticized by BAUMGARTNER et al.(1985).
A synthetic and functional map of the urban climate based on a detailed analysis of the micro- and mesoscale conditions (there are already a growing number of examples) should give detailed information on at least the following three factors (KUTTLER & SCHREIBER 1984):
1. the location and intensity of over-heated areas in the municipal area
2. records of areas with cold air sources
3. records of the courses of cold-air fluxes into areas with excess heat

These charts could then form the basis of maps illustrating the importance of the factors climate and air-hygiene and could serve as a source of information for town planners (STOCK et al. 1986).

8. FURTHER DEMANDS ON AN APPLIED URBAN CLIMATOLOGY

The demands made by urban climatologists and town planners can be summarized as follows (FRANKE 1977, ERIKSEN 1980, KUTTLER & SCHREIBER 1984, WANNER 1986):
1. The temporary excess-heating of downtown areas in summer must be prevented or - at least - be reduced considerably. This can be realized by an increased coverage of vegetation. The two main questions here are:
- "How large must the green-area in the municipality be to have the desired effect?" and
- "How can the green-area be designed to be climatically most efficient for its environment?" (POTTHOFF 1984).

In this field v. STÜLPNAGEL (1987) carried out a detailed examination using the City of Berlin as an example.
Examinations carried out by HORBERT et al.(1985) in Berlin, showed that on extremely wind-still days with green-areas of 30 ha, temperatures fell in the immediate vicinity up to distances of from 150 to 600 metres. Under similar conditions, the influence of the 212 ha -"Tiergarten" could be measured up to a distance of 900 metres on its lee-side. SPERBER (1974), found, however, that although the measurable influence increases with the size of the green-area, the decrease in temperature even with large green-areas can only be determined up to a distance of about 250 metres. Nevertheless, the positive influence of such large green-areas on the cleanness of the air is much greater than their cooling effect (WILMERS 1985).

In this context we must not forget that the 'greening' of houses is of special importance. Intentional planting of creepers on the outer walls of houses and a 'greening' of roofs could be used as a not inconsiderable area for climatic melioration - without having to use additional land (HOYANO et al. 1985, YAMASHITA 1980).

2. The air-exchange inside the municipal area must be guaranteed as follows: Firstly by keeping aisles for fresh air free, through the optimum positioning of building structures in relation to important air flow systems (i.e. to the most frequent wind direction, the lowest air exchange and the periodical wind systems of a day)
and Secondly by restricting the height of building structures to only a few floors and also by restricting their width.

3. The share of particles and gaseous pollutants in the air must be reduced through furthering the use of heating systems in compound networks, filters in smoke stacks and catalytic converters.

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