Quelle: Berichte des Meteorologischen Instituts der Albrecht-Ludwigs-Universität Freiburg Nr. 18, März 2009 – 5th Japanese-German Meeting on Urban Climatology, Freiburg, Oktober 2008, S. 313-319

Urban climate and global climate change - a case study of the 'Ruhr area', Germany

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Abstract

The estimated rise of the global surface temperature during the course of the 21st century will have regionally varying impacts. Urban areas which are differentiated from their rural surroundings by severe surface sealing, poor air quality and high population density are not only sensitive to global warming but also they are major net sources of anthropogenic CO_2. This paper reviews likely impacts of global warming on urban climate and discusses potential mitigation and adaptation strategies as a case study for the Ruhr area, Germany.

1. Introduction

On the basis of the results of the IPCC, it must be assumed that anthropogenic climate change is chiefly caused by CO_2 emissions and that further increases in the global average temperature are to be expected (IPCC, 2007). The resulting effects on general atmospheric circulation and the heterogeneity of the earth's surface lead to regionally varying deviations from the predicted temperature rise. Research in this context should concentrate on regions especially affected by climate change. Among other areas, these include urban agglomerations which are strongly differentiated from their surroundings by severe surface sealing, poor air quality and high population density. It is the task of urban planning to influence local climatic conditions and therefore the predicted effects of climate change. Taking the example of the Ruhr area in western Germany (5,000 km², about 5 million inhabitants, Cfb climate according to Köppen), this paper describes the expected effects of climate change and the local counter-measures that can be taken.

2. General impacts of urban climate change in the Ruhr area

In 2007, CO_2 emissions from anthropogenic sources in Germany totalled about 861 million tonnes, or 2.7 % of estimated global emissions of 31 billion tonnes (Federal Ministry for Economic Affairs, 2008). Power plants account for about 40 % of emissions in Germany with the remainder evenly distributed between industry, home heating and traffic.

For the Ruhr area and central Europe as a whole, it is expected that the impact of global climate change will be as follows (after IPCC, 2007, changed and supplemented):

- increased frequency of clear and calm weather conditions with higher frequency of UHI events,
- modified spectrum of air pollutants (e.g. increasing NO_2 and O_3 concentrations),
- less summer, more winter precipitation,

- more thunderstorms in summer with intense rain events (flooding) and driving rain on house walls (higher pollutant fluxes),
- rising frequency of intense rain events,
- larger number of days exceeding thermal threshold values,
- eectric power consumption will increase at higher temperatures because of the higher number of air conditioning systems in use.

Climate change will not only result in a change in near-surface thermal conditions but also in the type, frequency, duration and air mass characteristics of meteorological situations. For example, it is assumed (Groß, 1996; Jacob and Winner, 2009), that low-exchange weather situations with more severe inversions will occur more frequently than have previously been the case, although there will be severe regional differences in the frequency of these situations. Such weather conditions are mainly connected with high pressure zones, associated in western Europe with low and predominant easterly winds. From the point of view of urban climatology, the effect will be an increase in the frequency of UHI events, with more pronounced temperature differences between urban areas and the surrounding countryside.

In addition, during sunny spells, especially in the summer months, it is expected that global radiation intensity and air temperature will increase as a result of the lack of cloud cover. As ozone production is positively correlated with these two parameters, ozone concentrations are likely to increase. These assumptions have been confirmed by model analyses and the results of measurement campaigns (Kuttler and Straßburger, 1999; Lin et al., 2001). In view of the increase in weather conditions dominated by high pressure, with low, mainly easterly winds and low turbulence as predicted above, it will be necessary to discuss whether high-emission industrial facilities should continue to be located at the eastern edge of urban areas. This siting recommendation, which has been favoured by planners to date but which has been subject to critical scrutiny for some time in view of current climate conditions (Schwegler, 1967), should no longer be given. On the contrary, industrial facilities should rather be located on the western edges of urban areas. As westerly winds tend to be more turbulent and atmospheric stratification tends to be less stable, sites on the western edge would ensure the more effective removal of pollutants from the area than is the case with sites to the east.

As regards future temperature changes, if the number of summer days ($t_{max} \geq 25$ °C) is taken as an indicator, it is expected for the climate station of the University of Duisburg-Essen in Essen (central part of the Ruhr area) that the number of these events will triple from the current value of 22 to 76 by 2100 if the assumed temperature increase is 3 K (Fig. 1).

The 2003 summer heat wave in Europe resulted in a significant increase in mortality (Souch and Grimmond, 2004; Jendritzky, 2007). It is therefore expected that more and more city-dwellers will decide to use air conditioning systems more intensively for home cooling, resulting in higher power consumption and CO_2 emissions. In the Ruhr area, it was found during the 2003 heat wave that power consumption rose at temperatures between 25 °C and 30 °C (Fig. 2), while there was a negative correlation at lower temperatures; this is confirmed by earlier studies (Kuttler, 2001).

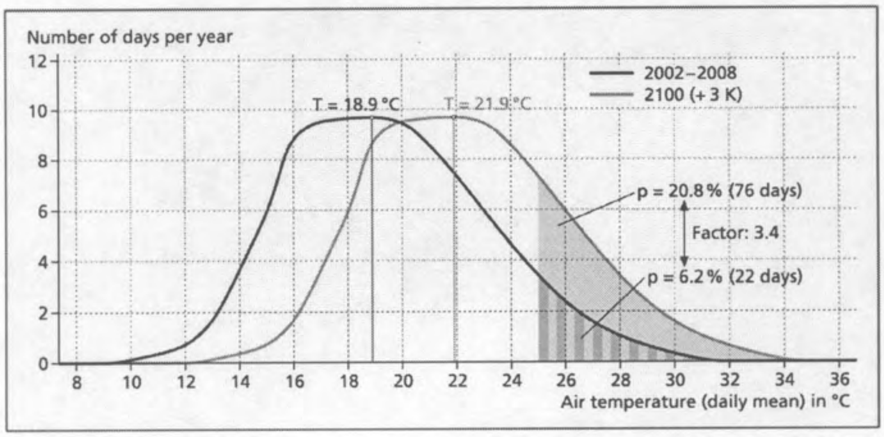

Fig. 1: Frequency distribution of daily mean air temperature (2 m above ground level) in Essen during summer months June to August for the current situation (2002-2008) and a 2100 scenario (station at Campus Essen, University of Duisburg-Essen)

If the frequency of heat waves increases, the ratio of summer to winter energy consumption is likely to shift from the current value of significantly lower than one to a value approaching unity, as demonstrated by model investigations for a comparable climate zone in the USA (Hadley et al., 2006). For the Tokyo agglomeration, simulations indicate an increase in energy consumption with rising temperature of 3 % K^{-1} (Genchi et al, 2003).

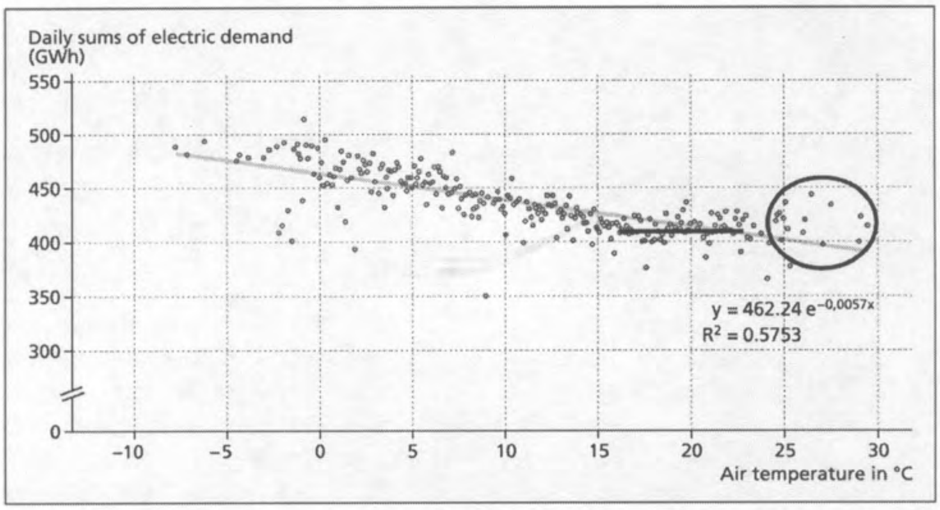

Fig. 2: Daily sums of electrical demand in dependence of air temperature (2 m agl, station at Campus Essen Jan 2001 - Dec 2005, electrical demand data courtesy of RWE).

3. Urban Counter-Measures

Measures to mitigate global climate change should especially be taken at the urban level. It is true that urban areas only account for about 2.7 % of the total surface area of the continents (United Nations, 2008). However, more than 70 % of the earth's population will live in towns and cities in the course of the 21st century (Heineberg, 2006). Urban areas are therefore a major source of net carbon dioxide emissions (Grimmond et al. 2004; Vogt et al. 2006).

Counter-measures in urban areas should have two main objectives: mitigation and adaptation. Mitigation includes measures such as minimizing carbon dioxide emissions and reducing radiation and air temperatures. Adaptation includes the process of taking up the opportunities offered by global climate change, for example by developing projects adapted to climate change on the urban scale and designing appropriate housing in towns and cities.

In order to minimize energy consumption and the resulting carbon dioxide emissions both in the summer (cooling) and in the winter (heating), development structures should give preference to a highly compressed, compact building style (well insulated buildings), with light house walls and multiple shading possibilities. In addition, urban settlements of the future should be based on short distances, with optimum connections to public transport in order to reduce or even render superfluous individual traffic. Furthermore, urban planners should pay attention to reducing urban sprawl as new residential developments in the surrounding countryside impair cold air production. Urban sprawl, is not only important in connection with informal growth in developing countries, where it is associated with slums. It is also increasingly evident in a number of cities in industrialized countries ("process of shrinking cities"; Oswalt and Rienietz, 2006).

The creation of the so called "blue and green" infrastructure in the Ruhr area should also be fostered. This includes for example increased planting of urban canyons, planting on facades and roofs and the creation of bodies of water. As biogenic VOCs such as isoprene and terpene are also precursor gases for ozone formation, plants which classed as low emitters (< 2 µg g^{-1} dryweight) of VOCs should preferably be used (Benjamin and Winer, 1998). Through shading and evapotranspiration, planted surfaces not only reduce surface temperatures but also air temperatures. In addition, if evergreen plants are mainly used in urban areas, they can also bind gaseous and particulate pollutants outside the vegetation period (Kuttler, 1982).

Direct measures to influence surface energy balances with a view to mitigating the heating of surfaces in the summer should consist in using bright, reflecting materials. This not only lowers surface temperatures, thus reducing long-wavelength radiation, but also reduces turbulent energy fluxes. Dark surfaces such as asphalted roads and tarred roofs, which can be heated to temperatures as high as 80°C as a result of strong solar radiation, emit 880 W m^{-2} of radiation in the long wavelength range alone. By using brighter materials and reducing the temperature of these surfaces to 50°C, for example, it would be possible to reduce radiation in this range by more than 250 W m^{-2}.

The use of renewable energy sources could also result in a reduction of CO_2 emissions. However, this would depend on the energy densities available in the climate zone concerned. The average yields which are possible are indicated below on the basis of a solar power plant and a wind energy facility which have been in operation in the Ruhr area for several years. The geothermal energy production data which are also given are based on model calculations. In order to compare the energy densities of solar and wind power plants, the values concerned have been referred to unit area (square metre).

The photovoltaic is a facility with an area of 1,000 m² installed facing South at an angle of 25° on a bus depot in Essen (central part of the Ruhr area). Assuming an average of 1450 hours of sunshine per year in Essen and an efficiency of $\eta = 0.15$, the facility generates about 96 MWh of electric power per year (August 2007 to August 2008). The specific energy density is therefore about 11 W m^{-2} (EVAG, 2008).

A wind energy converter installed on a 100-metre-high slag heap in the northern Ruhr area has a rotor diameter of 66 m and therefore a covered area of 3,421 m² for the purpose of power generation calculations. In 2007, this wind energy plant generated a total of 2.5 GWh of electric power. The specific energy density is therefore 83 W m^{-2}, almost eight times that of the solar power plant (Energieagentur NRW, 2009).

For power generation by geothermal systems, model calculations for the Ruhr area indicate that an energy density of 156 kWh m^{-1} a^{-1} could be available at a depth of 40 m. The specific energy density, referred to the length of the geothermal probe, would then be 18 W m^{-1} (Energieagentur NRW, 2009).

The yields of the renewable energy sources mentioned above indicate that the use of these sources is only feasible if large areas (for solar energy), large rotor diameters (for wind power) or long probes (for geothermal energy) are available. The operation of the solar power plant avoids 0.6 kg of carbon dioxide emissions per kWh of power generated. No values are available for the wind power and geothermal energy systems.

4. Conclusions

The temperature rise in the Ruhr area caused by the global warming will lead to a variety of climate changes, most of which will result in increased thermal stress for city-dwellers. It will only be possible to mitigate these effects if measures are taken at the local project and urban planning level. Targeted interventions in local radiation and energy balances will be key factors which will need to be quantified by measurements and numeric modelling. The results should be presented in climate function and planning maps (VDI 3785, P.1; 2008; Moriyama and Takebayashi, 2003) which should be drawn up using as large a scale as possible with a view to identifying climate and air quality hot spots and initiating appropriate counter-measures. In general, it will be necessary to carry out more intensive research concerning the effects of climate change on urban areas. Inter-disciplinary projects will be needed to obtain a comprehensive understanding of the interactions between city and atmosphere in various regions with different climate scenarios.

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