RESUMO

Os resultados mais recentes das simulações sobre a mudança climática prevêem um significativo aumento das ondas de calor durante o verão na Europa Central. Esta situação é intensificada localmente através do efeito da ilha de calor urbana, de modo que a qualidade de vida da população das cidades será influenciada mais frequentemente, por períodos mais longos e mais fortemente no futuro do que tem sido até agora. No contexto do princípio da precaução, o planejamento urbano deve desenvolver soluções para o problema, de maneira que no futuro, o que seria um aumento drástico do estresse térmico para as pessoas nos ambientes exteriores e interiores, seja reduzido a um nível tolerável. As bases de aplicação necessárias para tal estão sendo desenvolvidas por uma equipe interdisciplinar das áreas da climatologia urbana, planejamento urbano e geoinformática, no Projeto KLIMES. Nas análises experimentais, levantamentos e simulações sobre o conforto térmico das pessoas, módulos esquemáticos, adequados para aplicações práticas em planejamento urbano adaptado ao clima, são desenvolvidos e sumarizados num manual. Foram selecionados como sítios de investigação quarteirões urbanos de cidades da Alemanha, tomados como casos típicos de planejamento e desenho urbanos em nossa região climática. Mapas climáticos urbanos em nível de microescala e análise de condições térmicas são elaborados para oferecer a planejadores e arquitetos recomendações para projetos que mitiguem os efeitos adversos das mudanças climáticas.

PALAVRAS CHAVE: Clima urbano. Mudança climática global.

ABSTRACT

The most recent results of simulations on climate change predict a significant increase in heat waves during the summer in Central Europe. This situation is locally intensified as a result of the effect of urban heat islands. Given this phenomenon, the quality of life of the populations in the cities will be more frequently impacted by warmer periods that are longer and stronger in the future than seen until now. With such concerns rising, urban planning should develop solutions for the problem, so that in
the future, possible drastic increases in thermal stress, for those in indoor and outdoor environments, might be reduced to tolerable levels. The foundations for such necessary applications are being developed by an interdisciplinary staff in the areas of urban climatology, urban planning and geoinformation in the KLIMES Project. In the experimental analyses carried out, findings and simulations regarding the thermal comfort of humans and schematic models, adequate for practical applications in urban planning concerned with climate, are developed and summarized in a manual. Urban quarters in German cities were the sites of investigation since they were considered to be typical cases of planning and urban design in our climatic region. These studies develop urban climate maps, on a microscale level, and analyses of thermal conditions with the intention of offering planners and architects recommendations of projects that mitigate the adverse effects of climate changes.


RESUMEN

Los últimos resultados de las simulaciones sobre el cambio climático prevé un aumento significativo de las olas de calor durante el verano en Europa Central. Esta situación se intensifica a nivel local por el efecto de isla de calor urbano, de manera que la calidad de vida de la población urbana se verán afectadas con más frecuencia, durante más tiempo y más fuerte en el futuro que hasta ahora ha sido. En el contexto del principio de precaución, la planificación debe desarrollar soluciones para el problema, de modo que en el futuro lo que sería un drástico aumento de estrés por calor para personas en los exteriores o interiores, se reduce a un nivel tolerable. Los fundamentos de la aplicación necesaria para esto están siendo desarrollados por un equipo interdisciplinario en las áreas de la climatología urbana, planificación urbana y geoinformática, en el Proyecto KLIMES. En experimentos de laboratorio, estudios y simulaciones acerca del confort térmico de las personas, módulos esquemáticos, adecuados para aplicaciones prácticas en la planificación urbana adaptada al clima, se desarrollan y se resumen en un manual. Fueron seleccionados como lugares de investigación unos bloques de ciudades en Alemania, tomados como casos típicos de planificación y diseño urbano en nuestra zona climática. Mapas del clima urbano a nivel micro y análisis de las condiciones térmicas están diseñadas para proporcionar a los planificadores y arquitectos recomendaciones para proyectos que mitiguen los efectos adversos del cambio climático.

PALABRAS CLAVE: clima urbano, cambio climático global.

1. INTRODUCTION

According to recent studies concerning climate change an increase of temperature in Middle Europe is predicted. This background situation is intensified by the urban heat island effect with the consequence that the quality of human life in urban quarters will be affected more frequent, over longer periods and stronger in the future. In this context human comfort is coming to the fore. As cities throughout
Middle Europe have been more concerned about accumulation of heat in the past there is supposed to be potential of heat stress. The aim of the project KLIMES (Strategies and concepts for urban planning to mitigate the impacts of climate extremes on well-being and health of people in cities — KATZSCHNER et al., 2007), is to develop planning strategies to ensure outdoor human thermal comfort during extreme heat waves in the summer, taking into account existing urban structures. The research design covers various methods which are carried out by different work groups. The present paper presents the particular project doing experimental investigations of the microclimatic conditions and parallel interviews with people on the site of their thermal perceptions.

Figure 1 shows an urban climate analysis to locate the urban heat load (urban heat island) and to give further information for any microclimatic studies as well as the location of the increased air temperature in a city. The increase of thermal uncomfortable conditions judged by interviewees and their localization should be the start for any new urban development strategies.
2. METHODOLOGY

The approach was to evaluate influences of certain urban structures or elements on human thermal comfort conditions. This was realized through measurements with a temporary reference station and two mobile recording systems by the subproject from Freiburg University. The meteorological parameters are air temperature, wind and humidity, but also radiation coming from all 6 sides. Furthermore another mobile system was used, measuring the same parameters but only where interviews were carried out (subproject University Kassel). Using this methodology every person and
its subjective perception can be related to objective data of the mobile station. The mobile station measures three minute means of meteorological data being transferred into the thermal index. As thermal parameter the Physiological Equivalent Temperature (PET) was used, which is based on the heat balance of man from Höppe (2002) and is calculated with air-, mean radiation temperatures, wind and humidity. Finally there one gets a PET value for each participant of the interviews.

Investigations were carried out in the city of Kassel, situated in the central part of Germany. The microclimatic conditions include mesoscale informations of the urban heat island and ventilation. The microclimatic maps are zoomed information from the overall pattern. Important effects for the thermal comfort are building structure, surface conditions and ventilation. On this level every interviewee could be devoted to a certain space and therefore certain microclimatic conditions.

From Figure 2 the principle procedure to evaluate urban climate can be seen. First step was a detailed urban climatic map with thermal comfort zones from hot to cool. This was derived from measurements and a GIS calculation, where the heat budget of surfaces, walls and cooling potential from air mass exchange come together to a classification of PET values. Second information came from interviews, where people’s sensation was directly compared with their thermal environment. By this method comfortable and uncomfortable areas could be deducted. The third step was a concrete planning proposal using vegetation implementations. The locations of design actions are marked by the arrows showing the areas to reduce long wave radiation from walls and mitigate direct sun radiation at one side. The advices aim to improve the thermal comfort conditions in the sense of having an inhomogeneous microclimate for any choice. Here especially mitigation of heat loads near facades and uncomfortable situations are taken up and solved by using green facades and
small trees. The very comfortable conditions in the open space at the mid region are kept. Only on this base, projecting future scenarios on how the global climate change will affect the microclimatic conditions, useful adaptation methods can be done.

3. RESULTS

Microclimatic maps of Kassel (Opernplatz) were produced. They were developed from small scale measurements and a calculation with ENVIMET software. Looking for the hottest period in summer in both cities the maxima were avoided from people’s usage. Shadow if possible and areas with wind seems to be comfortable in the range of a PET value between 30°C and 50°C. Different is the situation during cloudy conditions where one can see that the decrease of PET does not automatically leads to a more neutral thermal sensation, but decrease the heat stress.

![FIGURE 3 - Thermal conditions of the Opernpatz Kassel indicated by the PET value.](image)

Although heat stress can be defined with values of more than 35°C PET, for thermal sensations people’s behavior is much more tolerant. Looking for benchmarks of thermal comfort in outdoor situations is quite difficult as people can look for comfortable places if their suffering is high. Nevertheless the analysis of percentages shows that PET values of more than 30°C affect discomfort and heat stress. The first sentence means that planners should look for inhomogeneous microclimates and the second one means definitely to plan for more heat reduction mainly through shadow. The outlook to see how these new urban space conceptions affect the buildings inside will become more and more important.
Figure 3 shows the areal thermal comfort analysis of the open space, while in figure 4 the daily course is plotted from the ENVIMET® model compared to the spot measurements. From that one can see that measurements and modelling match the result of thermal comfort quite good. The graphs show the daily variation of the thermal index (PET) on the left from the software calculation and on the right from measurements. The wind speed as an important factor for thermal comfort makes the measured data more variable. In principle the daily variation from the model ENVIMET® compared with the spot measurements were sufficient (Figure 4). The spatial distribution as well as the daily course is presented well, so that the results could be taken for the interviews.

![Graph of Thermal Comfort Index (PET) from modelling and measurements.](image)

![Bar chart of Thermal Comfort Sensations during midday to evening with the meteorological parameters from Figure 4.](image)
The thermal sensation of people during the day shows a mean of hot to very warm situation. But if one look to the daily course the behavior and the sensation changes (Figure 5). Especially the cooling during evening seems to be seen as the most important factor. Hot and discomfort situation decrease in the evening hours. This is due to the reduced radiation as well as wind by that time also was reduced.

![Figure 5](image)

**FIGURE 5** - Daily course of the thermal sensation of people.

For an open space in the city centre the urban climate conditions were changed in the model following global climate variation scenarios (Figure 6). The data came out of the so called CLM (Community Land Model) scenario 2040. Microclimatic conditions then changed mainly through increased radiation values. As result the PET value increases up to 10°C in the shadow and up to 20°C in the sun. For planning purposes creating shadow situations to decrease the incoming short wave radiation and using reflecting materials to decrease long wave radiation should be the first priority. Secondly the inhomogeneous microclimatic situation should be kept in order to give people the chance looking to their personal optimal environment.

![Figure 6](image)

**FIGURE 6** - Increase of heat stress (PET value) under intensification of the global radiation.

For an open space in the city centre the urban climate conditions were changed in the model following global climate variation scenarios (Figure 6). The data came out of the so called CLM (Community Land Model) scenario 2040. Microclimatic conditions then changed mainly through increased radiation values. As result the PET value increases up to 10°C in the shadow and up to 20°C in the sun. For planning purposes creating shadow situations to decrease the incoming short wave radiation and using reflecting materials to decrease long wave radiation should be the first priority. Secondly the inhomogeneous microclimatic situation should be kept in order to give people the chance looking to their personal optimal environment.

Of course in very dense cities the main city fabric cannot be changed. Therefore small scale actions are needed and the effects from that are to be studied. Figure 7 proofs the effect of the different surface temperatures in comparison to a reference station. Under the same Urban Canopy Layer (UCL) conditions the surface

![Figure 7](image)
conditions can influence the microclimatic conditions considerably. All obstacles had different surfaces and the measured surface temperatures can be obtained in the figure below. Under the same meteorological conditions surface temperatures as well as air temperatures in 40 cm distance vary substantially. The information of which surface materials should be used in open spaces in order to give enough heat loss during nights might be valuable for urban design specifications. Differences in cooling at these experiments were up to 10 degrees in surface temperatures and 6 degrees in air temperature in 40 cm distance, under the same UCL conditions.

**FIGURE 7** - Experiments with different materials and the corresponding surface temperatures.

In order to develop quantitative proposals more measurements are needed to explain the effect of materials, orientation of buildings and surfaces. Therefore an experiment in Kassel was carried out to compare different instrumentations and to see wall effects at the same time (Figure 8). The mean radiant temperature was calculated from the vertical and horizontal radiation measurements as well as from different globe thermometers (sizes and colours). The mean radiant temperatures calculated from the globe thermometers had to be recalculated to diminish the wind factor and the diameter of the globe. The graphic at figure 8 shows the measured mean radiant temperature on the 23rd of June 2008, a radiation type of weather. The results show that the mean radiant temperatures calculated from the two different globe thermometers are similar to the mean radiant temperature calculated from the vertical/horizontal radiation measurements.
What can be seen very clearly is the shadow effect. When the sensor gets shaded the mean radiant temperature drops immediately due to the decrease in short-wave radiation. So this situation alone makes the decrease of the mean radiant temperature of nearly 20 degrees. The same situation exists during the day when the small globes become shaded at 3:30 and 3:45 p.m.

![FIGURE 8 - Daily variation of mean radiant temperature from flux measurements and globe thermometers on mean radiant temperature on the 23rd of June 2008 with an experimental design of different globe thermometers and horizontal flux measurements.](image)

4. ASPECTS OF GLOBAL CLIMATE CHANGE

Looking to the global climate change and the expected increase of temperatures of 2°C cities will suffer even more. As studies in the context of urban heat islands (UHI) have been showing, the differences between the city centre and its outskirts can reach more than 5°C during night hours, so this might to be extended through global warming. Especially the increase of income radiation will lead to more heat storage and to a more intensive UHI. Aim should be to reduce income radiation during the day by using reflective materials (see Figure 7) and less building heat storage.

To evaluate urban heat island situation the frequency of hot days is counted. This again can easily be developed using scenarios of global warming. Figure 1 showed the increase of hot days during the period of 1950 to 2005 of a middle size city located in central Germany in a spatial distribution with the increase of hot days. Most of the areas are affected.
Other example, an increase of hot days with more than 25°C in urban areas was calculated on a base of 46 days a year in Frankfurt, Germany, presently with:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- open spaces outside the city:</td>
<td>+3 days</td>
</tr>
<tr>
<td>- city parks inside built-up areas:</td>
<td>+4 days</td>
</tr>
<tr>
<td>- residential areas:</td>
<td>+6 days</td>
</tr>
<tr>
<td>- densely built-up areas:</td>
<td>+11 days</td>
</tr>
</tbody>
</table>

For the city of Frankfurt these developments were calculated from now to 2040 and presented in a spatial distribution showing the influence of neighborhoods. Background scenario was a global climate change of 2°C. The areas of heat stress increased considerably and were moreover strengthened by the urban heat island. One can see that heat stress will occur very frequently with more than 35 days per year. That means that most of the city becomes a problem area with high heat load especially in densely built up areas with an increase of 11 days with heat stress. Summer days and also summer nights will be under heat stress conditions. Recreation areas will be too far away to be in walking distance. Traffic increase with air pollution problems will follow.

5. CONCLUSIONS AND OUTLOOK

The perception of places concerning its thermal comfort is closely linked to psychological matters. Its outer appearance influences thermal comfort as well as, for example, the people's attachment to a place (KNEZ, 2005; KNEZ e THORSSON, 2006). So thermal perception does not only rely on the microclimate but is also dependent on psychological issues. Further studies show that a high variation of microclimates tends to be evaluated positively (KATZSCHNER, 2006).

One central issue of the Project KLIMES is to evaluate whether certain urban structures affect heat stress more than others, concerning the microclimate on the one hand and the subjective perception on the other hand. So, for instance, a fountain rarely affects the microclimate but it does influence the subjective perception as being felt cooler. Thermal conditions are dependent on buildings, surface conditions and open space obstacles causing climates from very hot to cool in the summer period. Therefore, taking into account psychological issues, variation of microclimates and the microclimate itself, guidelines should be found, including issues drawn from all disciplines.
There is previous evidence (RUROS, 2004) that there are two dominant factors affecting thermal sensations in outdoors. One is the mean radiation temperature and the other is the wind speed. Especially higher wind speed seems to be negatively perceived by people living in moderate climates but positively perceived in warmer climates. Considering the predicted increase of temperature, and first findings from KLIMES approve of that matter, wind is becoming more important in our regions and should be taken into account in further planning.

Future city developments under the consideration of climate adaptation aspects have to consider how people use open spaces and how this is connected to heat conditions. As seen in Figure 2 people avoid warm places in summer conditions. Shadows are used intensively. The calculations can do an analysis from the actual situation but as well could give perspectives for the change of the thermal situation through materials or structures. Focus should be given to facades, shadow and sufficient ventilation.

Thermal situations moreover should be considered always in connection to the use of open spaces. The interviews of thermal sensations suggest a very inhomogeneous microclimate as the best conditions for people. During hot summer days shadows as well as moderate microclimates are needed in walking distances. Open spaces here are used for communication as well as recreation next to the houses. The analysis can be obtained from ENVIMET® simulations. Cool areas or warm areas as seen in Figure 3 are used to qualify open space planning.

Like Figure 9 is proposing open spaces should be analyzed according to their use in dependence of thermal comfort conditions. The picture shows an area in the middle of the campus at Kassel University. During this hot summer day only walking use was done in the sun since the vegetation in the warm area in the middle of the campus is not sufficient to cool down the area. Activities such as communication or recreation were made by the students at the campus only next to the houses shadows during this day. The ENVIMET® calculation estimates the cool areas and the warm areas. With that the inhomogeneous characteristics can be shown and the design actions can be qualified.
FIGURE 9 - Behaviour of people in an open space and the corresponding thermal conditions through an ENVIMET calculation.
REFERÊNCIAS


