

Chapter 8

Urban Climate Strategies Against Future Heat Stress Conditions

Lutz Katzschner

Abstract Recent climate change studies predict an increase of temperature in Central Europe. These conditions – intensified by the urban heat island effect – are expected to have consequences on the quality of human life in urban areas in the future. Urban design must respond to these changes in the urban climate and, by following the precautionary principle, must ensure that in the future thermal stress for people outdoors and indoors is reduced to a tolerable degree. The application-related basics needed for this have been developed by an interdisciplinary team from the fields of urban climatology, urban development and geoinformatics. This project aims to develop strategies and concepts for urban planning to mitigate the impacts of climate extremes on the well-being and health of city residents. In experimental analyses, surveys and simulations on the thermal comfort of people, and draft modules suitable for practical application in urban planning adapted to the climate, have been developed and summarised in a manual. Urban quarters in Germany, Brazil and Hong Kong have been selected as examinations sites.

Keywords Thermal comfort • Thermal sensation • Urban climate

8.1 Urban Climate and Thermal Comfort

According to recent studies on climate change, an increase of temperature in Central Europe is predicted. This change is intensified by the urban heat island effect, which is expected to affect the quality of human life in urban quarters with greater intensity in the future. The issue of human comfort in relation to existing urban structures is coming to the fore (Katzschner et al. 2007), along with a growing recognition of the

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need for planning strategies that ensure outdoor human thermal comfort during extreme heat waves.

Recently, there has been strong public interest in the quality of open urban spaces. As part of the growing discussion over the concept of new urbanity, the issue of revitalizing cities has become more and more important. Therefore, in order to increase the use of outdoor space and follow the idea of revitalising cities, environmental conditions and thermal comfort – both of which affect people using these spaces – have to be considered and improved.

To understand thermal comfort and its effects on human beings, air temperature is not an adequate indicator. Instead, thermal indices should be used. In this study, the physiological equivalent temperature (PET) is used to calibrate urban climate classification in different climate areas and the urban climatic maps (Ng 2010). Figure 8.1 show an urban climate analysis of heat load in Frankfurt and Hong Kong. To evaluate the urban heat island situation, the frequency of hot days above 25°C were counted. The classifications in Fig. 8.1 of the urban climatic maps are based on the thermal heat load expressed as the index PET, which was evaluated through the results of interviews concerning the thermal sensation of people. To account for the increase of hot days in the future, scenarios of global warming can be used.

Regarding the increase of hot days and their spatial distribution during the period of 1950–2005 in the city of Frankfurt (see Fig. 8.2). In Germany, cities like Frankfurt show an increase in the number of hot days – though this trend is not distributed equally throughout the city. Variations in density across the city affect heat load and therefore have different air temperature increases. In Frankfurt, people have been observed to complain after experiencing 46 days of temperatures above 25°C, while in Hong Kong, for instance, this is accepted as a normal occurrence, where air temperatures greater than 25°C occur an average of 255 days of the year. This indicates that thermal comfort should be considered according to regional climates.

As studies of urban heat islands (UHI) show, differences in temperature can vary by more than 5°C during night hours. This situation is aggravated by global warming (Katschner et al. 2009). An increase in incoming radiation can lead to greater heat storage, contributing to intensified UHI. To demonstrate this in terms of thermal comfort, the index PET (Höppe 1999) gives a thermal evaluation. Moreover, PET provides a better understanding of the influence of radiation and wind speed on thermal comfort and heat stress, which enables planners to respect these factors in their urban design.

8.2 Methodology

To develop strategies in urban design, urban climate conditions need to be classified as in Fig. 8.1. At the same time, however, an evaluation should be carried out in order to judge future trends in heat load. Therefore the urban climate

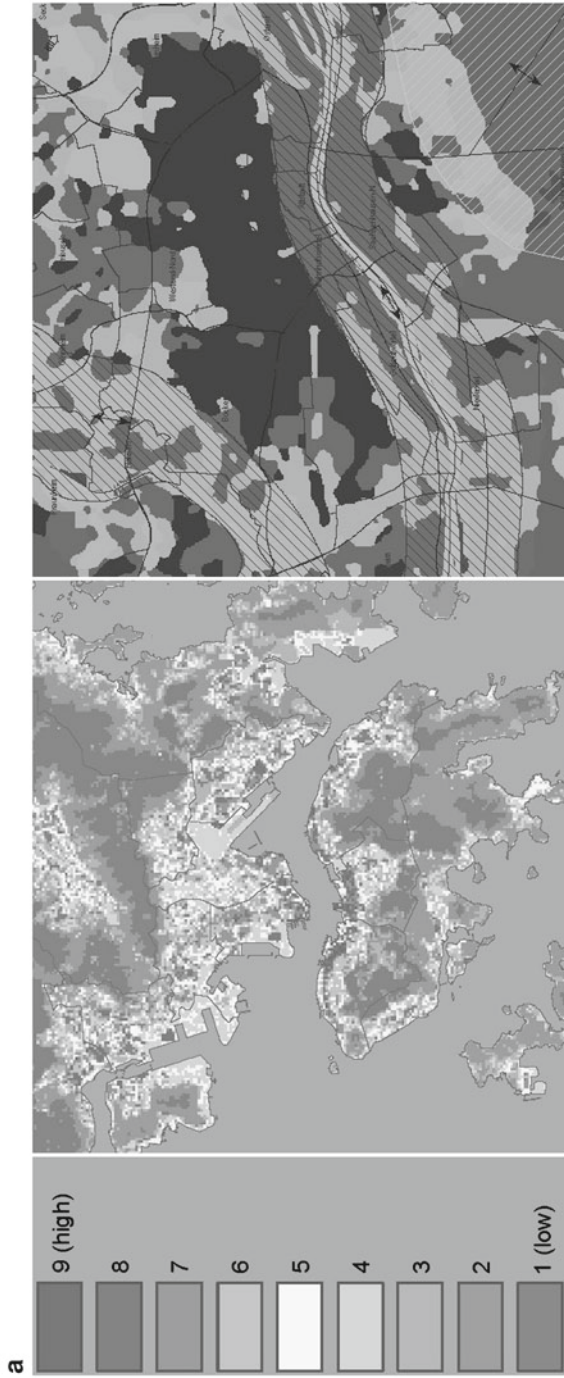


Fig. 8.1 (a, b) Urban climate analysis of heat-load in Frankfurt and Hong-Kong

b

| classification | name | description | PET | evaluation |
|----------------|------------------------------------------------------|-------------------------------------------------------------------|------|-------------------------------------------------------------------------------------------------------|
| 1 | fresh air productions or air path | minor roughness and minor heat capacity mainly agricultural areas | 22 C | very important for climate, high protection |
| 2 | fresh air production on slopes | forests and trees | 24 C | important for circulation to keep and maintain |
| 3 | mixed climates with local circulation pattern | parks, gardens | 26 C | important linkage areas, foresee the orientation and density |
| 4 | heat island potentials | urban areas with roughness but vegetation links | 28 C | thermal air pollution problems, mitigation through ventilation and vegetation, heat stress increasing |
| 5 | heat island | dense built up areas with considerable roughness and heat load | 30 C | heavy thermal load should be mitigated, heat stress problems, extremely increasing |
| 6 | heat island max | extremely dense areas nor vegetation (city centre) | 32 C | heavy thermal load should be mitigated, heat stress problems, extremely increasing |

Fig. 8.1 (continued)

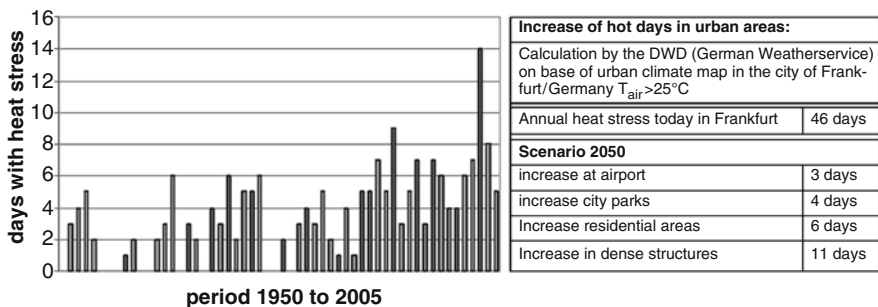


Fig. 8.2 Increasing number of hot days ($t_a > 25^{\circ}C$) in the city of Frankfurt (1950–2005) and increase taken a scenario depending on city structures

classifications were calibrated by PET values. Calculations of spatial distribution on urban heat load based on radiation balance and the dynamic pattern based on roughness length were linked with interviews to gather information on people’s perceptions. Carrying out on-site interviews and parallel meteorological measurements at the exact same point ensures a direct comparison of subjective and objective data.

This was achieved through mobile meteorological measurements together with interviews with a temporary reference station and two mobile recording systems. The meteorological parameters measured were air temperature, wind and humidity, as well as horizontal and vertical radiation. Using this methodology, every person’s subjective perception can be related to objective data collected by the mobile station. The mobile station measures meteorological data as mean values of 3-min intervals, which is then transferred into the thermal index PET.

The index PET was chosen for various different reasons. First, it is conveniently adapted to outdoor settings. Second, it is widely used at an international level, which allows for comparison and replicability. And third, its required parameters are easily calculated. Additionally, the use of Celsius is a widely accepted unit as an indicator of thermal stress and thermal comfort; this makes the results easy to communicate and comprehensible for potential future users.

PET is a steady-state model involving all heat exchange processes between the human body and its environment. PET evaluates the thermal conditions in a physiologically significant manner. It is defined by Höppe (1999) as ‘the air temperature at which the human energy budget for the assumed indoor conditions is balanced by the same skin temperature and sweat rate as under the actual complex outdoor conditions to be assessed.’ The meteorological input parameters include mean radiant temperature (T_{mrt}), air temperature (T_a), wind speed (v) and vapor pressure (RH). PET enables various users to compare the integral effects of complex thermal conditions outdoors with their own experience indoors. PET also considers the heat transfer resistance of clothing and internal heat production.

8.3 Evaluation of Thermal Comfort Conditions

To study thermal comfort, the benchmarks of indices have to be considered depending on the regional climate and the urban situation. Therefore, it is not possible to only refer to one index value worldwide. A calibration of PET, using ordinal regression analysis, applying data from Hong Kong, Brazil and Germany, shows differences in perception concerning heat stress. Mobile measurements and interviews were conducted in two different climates during different seasons in Germany and Hong Kong. The data were used to calibrate the PET (Table 8.1).

To calibrate the PET value, ordinal regression analysis was used following the assumption that the measurement scale – very hot, hot, warm, comfortable, slightly cool and cool – have different intervals. This means the cut off point from very hot to hot is defined differently than the interval between hot and warm (Fig. 8.3). Due to this non linear relation, then, it would not be accurate to use linear regression analysis.

While the comfort zones vary between the different climates by 6°C PET, it is obvious that in the warmer categories differences decline (Table 8.1). Differences are also due to the fact that in the study of Germany, four categories measuring heat stress were used, while in the subtropical climate, only three were used. So the subjective perception of hot – i.e., high heat stress – in both climates start around a value of 35°C (PET).

Since we are interested in the conditions of heat stress, the most important value is the benchmark between comfortable and warm, as this represents the point at

Table 8.1 Calibration of PET (°C) in Germany (n = 776), Hong Kong (n = 1,958) and Brazil (n = 706) based on empirical data

| PET (°C) (Germany) | PET (°C) (Brazil) | PET (°C) (Hong Kong) | Subjective perception | Level of stress |
|-----------------------|----------------------|-------------------------|--------------------------|----------------------|
| More than 42 | More than 43 | More than 45 | Very hot | Extreme heat stress |
| 35–41 | 35–42 | 35–45 | Hot | Strong heat stress |
| 29–34 | 31–35 | 30–35 | Warm | Moderate heat stress |
| 18–28 | 26–30 | 12–30 | Comfortable | No thermal stress |
| 13–17 | – | 9–12 | Slightly cool | Weak cold stress |
| Less than 13 | Less than 13 | Less than 8 | Cool | Cold stress |

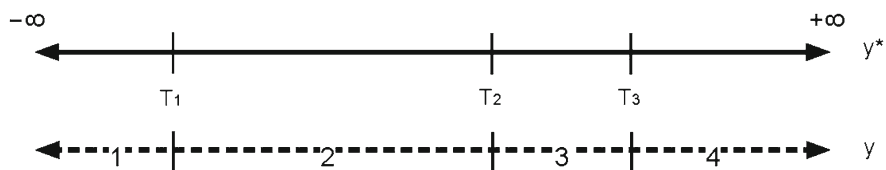


Fig. 8.3 Visualization of the differences concerning the cut points in the answering categories (Source: Nonnenmacher 2005)

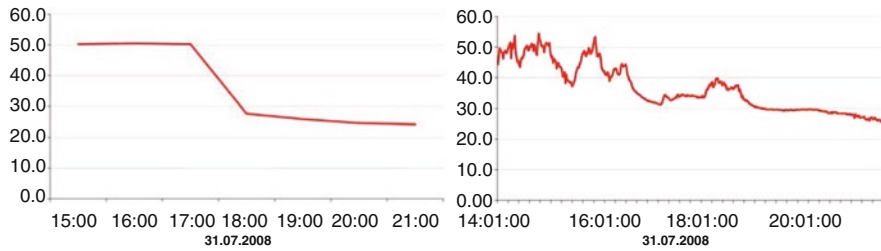


Fig. 8.4 Thermal comfort index (PET) from modelling and measurements

which heat stress begins. Therefore, 28°C (PET) in Germany, 30°C (PET) in Hong Kong and 31°C (PET) in Brazil can be determined. Values were very difficult to compare within the cool classification, since in Hong Kong nearly no cool sensation from interviews could be found. The main focus, then, was on the comfortable and hot zones where health risks are expected after a certain point.

On July 31, 2008, measurements were taken on the Opernplatz in Kassel. Figure 8.4 shows the daily course of thermal comfort using the meteorological model ENVI-met compared to the spot measurements. The graphs show a warm day with significant cooling in the late afternoon. These measurements match the result of thermal comfort. The graphs show the daily variation of the thermal index (PET) on the left and the conducted measurements on the right. Wind speed, an important factor in thermal comfort, is partly responsible for the observed variation in the data. In principle, the daily variation from the ENVI-met model compared with the on site measurements was sufficient accuracy for a thermal comfort evaluation.

The mean thermal sensations of people throughout the day showed comfortable to neutral conditions. However, behaviour and sensation were observed to change during the course of the day; as Fig. 8.5 illustrate, the cooling period during the evening seemed to affect thermal sensation, with a decrease in discomfort during these hours. This is due to reduced radiation and wind on this particular day. The situation during cloudy conditions is different. One can see that a decrease in PET does not automatically lead to a more neutral thermal sensation, but does decrease heat stress.

Further studies show that high variation in microclimates tends to be evaluated positively (Katzschner 2006). One central issue of the project is to evaluate whether certain urban structures affect heat stress more than others in terms of microclimate and subjective perception. Therefore, guidelines should consider the variations of microclimates inside urban structures (EU RUROS 2004). The factors which can be influenced by urban design include mean radiation temperature and wind speed. Higher wind speeds in particular seem to be negatively perceived by people living in moderate climates – though positively perceived in warmer climates.

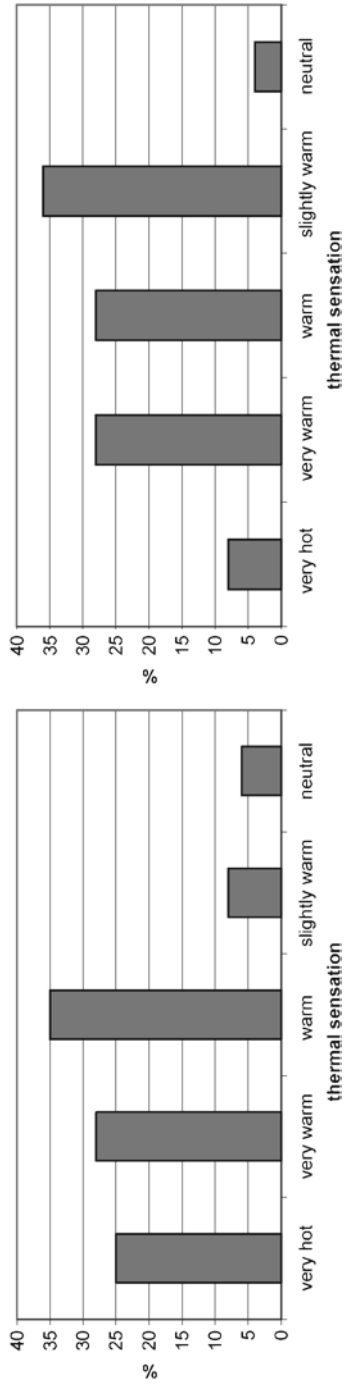


Fig. 8.5 Thermal comfort sensations from interviews before (*left*) and after (*right*) the cooling period at 4:30 p.m.

8.4 Urban Planning

For planning purposes, it is important to identify spatial patterns of heat stress in order to develop thermally comfortable areas. To accomplish this in Kassel, microclimatic maps of one urban area within the city were produced (Fig. 8.6). These were derived from small scale measurements and a calculation using ENVI-met. Heat stress can be defined as occurring at values above 34°C PET following the presented calibration (Table 8.1). The example of Opernplatz shows that people are very tolerant of heat stress as long as they have the choice between different microclimatic conditions. Nevertheless, the analysis shows that PET values of more than 30°C cause discomfort and heat stress. According to these findings, planners should create varied microclimates within their cities and encourage heat reduction through shading.

During the hottest period of summer in the city of Kassel people were observed to avoid locations that exhibited the highest temperatures. Shade, if available, and areas with wind seem to be comfortable in the range of 30–50°C PET. The spatial distribution of interviews conducted on Opernplatz in Kassel (Fig. 8.6) show this pattern of usage.

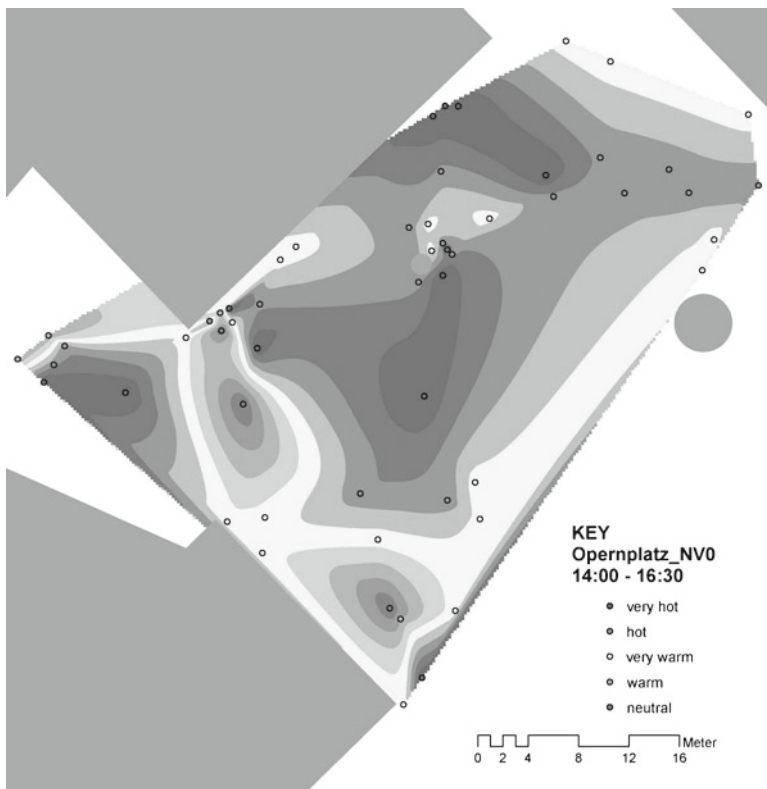


Fig. 8.6 Spatial distribution of thermal sensation from interviews in Kassel/Germany at 3 p.m.

Predictably, the hottest spots of the Opernplatz (which is exposed to the sun nearly all day) are avoided. As can be seen in Fig. 8.6, the Opernplatz is completely sealed and contains few trees that provide shade. To gain information from interviews that could be useful to planners, it was necessary to link the interviews with the distribution of PET values in this location to get the spatial distribution. To accomplish this, a simulation using ENVI-met was conducted and maps were generated.

The map simulated with ENVI-met revealed hot spots as well as recreational spots within Opernplatz. The subjective perception map aligned closely with heat sensitive areas. This, in combination with the calibration tables, is helpful advice for planners considering the redesign of urban open places, and is becoming even more important in light of global climate change and increased periods of heat stress.

8.5 Conclusion

Global climate change and urban climate cannot be dealt with separately. Urban heat islands and concomitant heat stress will increase. Therefore, urban planners will require more quantitative information to mitigate future stress conditions. As stated above, knowledge of microclimatic conditions need to be mapped so that measures can be taken to mitigate heat stress. For cities that aim to reduce their heat income during the day and retain their cooling capacity during the night, there are various options. The first can be achieved by using shade, reflective materials and thermally induced circulations. To achieve nightly cooling, adequate air mass flow is needed. While heat reduction can be achieved through open space planning – that is, by improving surface conditions, building orientation and building design – the issue of ventilation and local air mass exchange requires knowledge derived from urban climate analysis on a mesoscale. To introduce these aspects into the urban planning system, it is important to keep in mind that different scales require different approaches. Building design and open spaces can be integrated into neighbourhood and design planning, while ventilation has to be considered on the urban development planning layer.

Future city developments should also take into account the use of open space and how this is connected to thermal conditions. The simulations can help guide decisions for the improvement of thermal conditions through the use of materials and structural arrangements; for example, through the use of facades, shade and ventilation.

Thermal conditions should always be considered in terms of the specific use of a particular open space. The interviews on thermal sensations suggest that varied microclimates provide the best conditions for people. During hot summer days, shade and moderate temperature zones should be available within walking distance. Microclimatic analysis can be obtained from ENVI-met simulations and measurements so that bioclimatic designs of open space can be conducted.

References

- EU RUROS Project (2004) Design guideline open space planning and comfort. CRES, Athen
- Höppe P (1999) The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. *Int J Biometeorol* 43:71–75
- Katzschner L (2006) Microclimatic thermal comfort analysis in cities for urban planning and open space design, comfort and energy use in buildings. Network for Comfort and Energy use in Buildings (NCUB), London, www.nceub.or.uk
- Katzschner L, Bruse M, Drey C, Mayer H (2007) Untersuchung des thermischen Komforts zur Abpufferung von Hitze durch städtebauliche Konzepte. *Ber Meteorologischen Instituts Univ Freiburg* 16:37–42
- Katzschner L, Maas A, Schneider A (2009) Das städtische Mikroklima: analyse für die Stadt- und Gebäudeplanung, vol 31, Heft 1, Bauphysik. Ernst und Sohn Verlag, Berlin
- Ng E (2010) *Designing high-density cities*. Earthscan, London
- Nonnenmacher A (2005) *AG statistische methoden der sozialwissenschaften: ordinale regression*. www.metaanalyse.de. Cited 17 March 2009