Human-biometeorological assessment of a city in complex topography

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1 Objectives

This study analyzes the human-biometeorological conditions in a city in complex terrain in Western Europe under the aspect of heat:

1. Assessment of the urban heat island
2. Analysis of the intra-urban human-biometeorological differences
3. Quantification of different adaptation measures
4. Assessment of impact of climate change on thermal comfort

2 Introduction

Spatial and temporal differences of meteorological parameters between neighboring urban and rural areas are formed by changes of aerodynamic surface structure and radiation fluxes. Thereby, the urban heat island (UHI) expressed by air and surface temperature differences are the most prominent and world-wide studied characteristics. Human-biometeorological methods are used for analyzing the UHI for city dwellers and to support city planners. Thereby, the thermal perception of humans is considered as the integral effect of air temperature, wind speed, air humidity and radiation fluxes and expressed by thermal indices.

3 Study area

Stuttgart is the fourth-largest metropolitan region in Germany. The city center is located in a sink-like basin and is surrounded by hills (Fig. 1). City dwellers do not only suffer from strong UHI, but also from strong air pollution during weather conditions with low wind speed, mostly less then 3 ms^{-1} (Fig. 1).

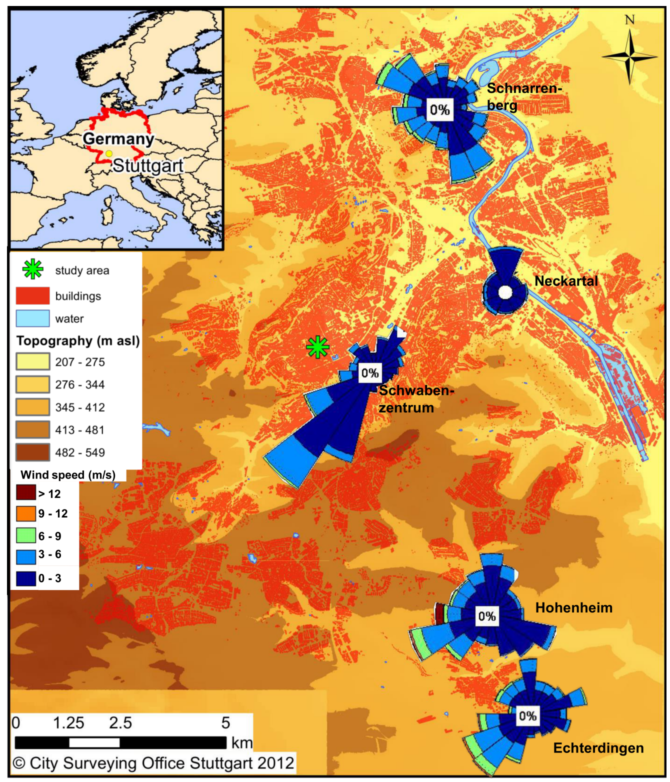

Figure 1: Topography of Stuttgart with wind roses at the different measurement stations.

Table 1: Key data of Stuttgart, Germany.

Population	600 000
Area	207 km^2
Devel. area	51.5 km^2
Elevation	207 - 549 m a.s.l.
Mean air temp.	11.8 °C
Precipitation	660 - 732 mm

4 Frame Project

This study is part of the transnational cooperation project 'Development and application of mitigation and adaptation strategies and measures for counteracting the global urban heat island (UHI) phenomenon'. It is implemented through the Central Europe program and co-financed by the ERDF.

5 Methods & Data

The Physiologically Equivalent Temperature (PET) is used to quantify the integral effect of meteorological parameters combined with the human energy balance and experienced by human beings. The micro-scale models RayMan (Matzarakis et al. 2007) and ENVI-met 3.1 (Bruse and Fleer 1998) in combination with TIC-ENVI-met (Ketterer and Matzarakis 2014) were used to simulate human-biometeorological conditions in terms of PET in Stuttgart. The analysis is based on measured data of German National Weather Service (DWD) and the municipality of Stuttgart, as well as data of a regional climate model (REMO) using A1B scenario.

6 Urban heat island (UHI)

The urban rural difference is calculated between the rural station Echterdingen (371 m a.s.l.) at the airport and the city center (Schwabenzentrum, 241 m a.s.l.), the river Neckar valley (224 m a.s.l.) and Schnarrenberg, a station, 5 km from the city center on the top of a SSW exposed hill (314 m a.s.l.) (Fig. 2). The average annual (maximum) $\mathrm{UHI}_{\mathrm{Ta}}$ is 2 (12) K in the city center. The average $\mathrm{UHI}_{\mathrm{PET}}$ is 3.3 K and maximum 20 K. The monthly maximum UHI occurs in winter in the city center due to anthropogenic heat production. However, at the UHI is maximal in summer considering hourly averages. The air temperatur differences are largest in nighttime, but the PET differences are highest in daytime.

7 Adaptation measures

Different scenarios of an area that should be rebuilt were analyzed using ENVI-met in combination with TIC-ENVI-met for a hot summer day. PET was found to be around 10 K lower under trees compared

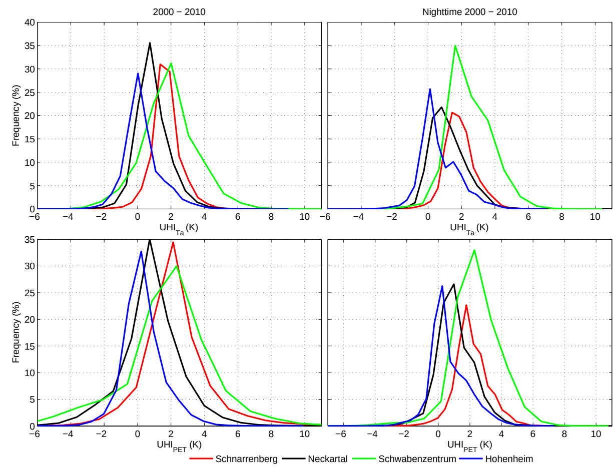

Figure 2: Frequency distribution of the UHI intensity at the four urban measuring site (see legend) and rural site Echterdingen from 2000 to 2010. Thereby, the UHI is analyzed using air temperature T_{a} (top) and PET (bottom).

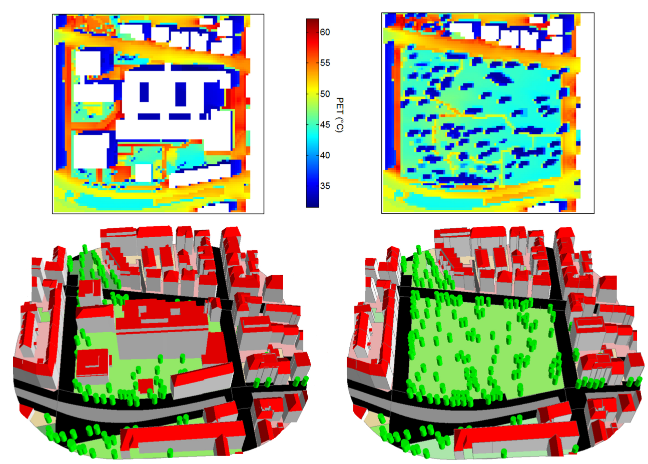

Figure 3: ENVI-met simulations of PET of the study area 'Olga-hospita' (location see Fig. 1) (left) and a park on the same area (right) on a hot summer day at 2 pm.

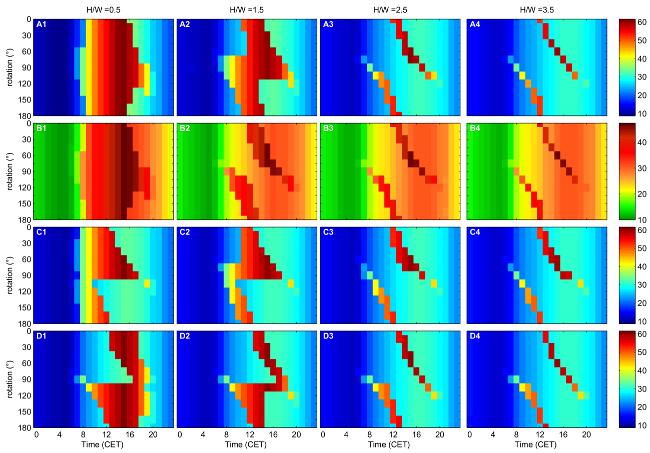

Figure 4: Changes in PET (panel B) and mean radiant temperature T_{mrt} in the middle of the street (panel A) as well as on both sidewalks (panel C and D) due to varying aspect ratio and orientation of the street canyon. The orientation changes from N-S (0°) to E-W (90°) to S-N (180°). Simulations were done with RayMan.

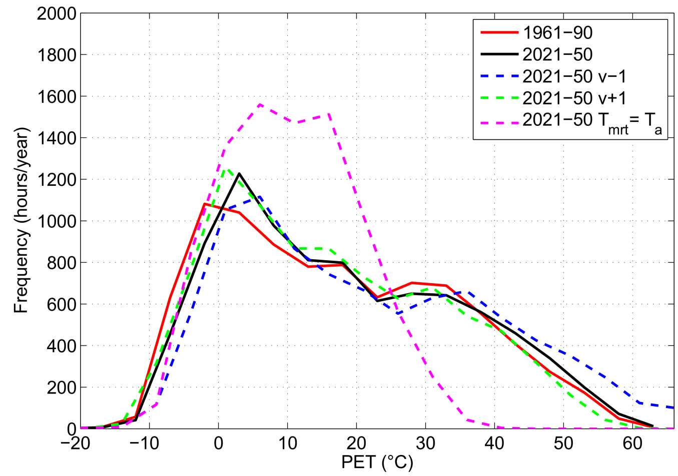

Figure 5: Hourly PET frequencies at 2 pm for the periods 1961-1990 and 2021-2050 based on REMO simulations with A1B scenario. PET was calculated for shaded areas ($T_{\mathrm{mrt}} = T_{\mathrm{a}}$) and with reduced and increased wind speed by 1 ms^{-1} (v-1 and v+1) for 2021-2025.

to green areas and 25 K lower than over sealed areas (Fig. 3). However, the mean differences are around 1 K in the depicted study area at 1.5 m height. Thermal stress can be reduced in a street canyon with a NNW-to-SSE orientation with a H/W ratio of at least 1.5. This allows also solar access during winter and maximizes the frequency of comfortable thermal conditions during the whole year (Fig. 4).

8 Climate Change

Heat stress (PET ≥35 °C is estimated to occur on 17 additional days (REMO, A1B scenario) until the end 21st century, but could be reduced by increase in wind speed by 1 ms^{-1} (Fig. 5).

9 Conclusion

- The UHI is mostly enhanced due to topography, besides during periods with inversions.
- The highest hourly UHI appears during summer as it is strongly radiation driven. However, the average monthly UHI is in the city center highest in winter due to anthropogenic heat fluxes.
- Regional climate models estimate a strong increase in the amount of days with heat stress, thus it is of vitally importance to implement adaptation measures.
- Adaptation measures like establishing green areas would reduce PET about 1 K (spatial average) and ≤ 25 K (special locations) at 2 pm.
- A NNW-SSE oriented street canyon with H/W ratio≥1.5 optimizes thermal comfort conditions throughout the year.

10 Future Research

Development of statistical methods to provide high-resolution climate evaluation maps for city planners in Stuttgart.

11 References

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