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High spatio-temporal monitoring of weather and outdoor thermal comfort in urban environments: A modular sensor network, first year data and outreach

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Timely information on the effects of the increasing intensity, frequency and duration of heatwaves on cities and critical infrastructure is needed for warning, emergency management and for developing context-specific climate adaptation strategies. Aside from the challenge of deploying sensor networks within built environments, there are hardly any operational city-wide networks that continuously measure and communicate human thermal comfort indices in public spaces.

To address this gap, a two-tiered weather and outdoor human thermal comfort monitoring network was developed and deployed in Freiburg in 2022. The monitoring network comprises a total of 42 automatic weather stations primarily mounted on public lamp posts at a height of 3 m, with the Tier-I network consisting of 13 customised stations, which are equipped with an in-house developed data logging unit optimised for this application, that is extend by a spatially dense but less complex Tier-II network consisting of 29 commercial weather stations. Both networks collect data on air temperature, humidity and precipitation, with the Tier-I network providing additional data on wind, radiation, pressure, lightning, solar radiation and black-globe temperature to calculate human-biometeorological thermal indices such as the Physiological Equivalent Temperature (PET).

Over the course of the first year of deployment (01-Sept-2022 to 31-Aug-2023), the stations have continuously collected high-resolution data (30 and 60 sec) with only little data loss. In a case study, the intra-urban differences in thermal comfort were analysed during the hot month of July 2023, in which five official heat warnings were issued by the German Meteorological Service (DWD). The results show expected intra-urban and urban-rural contrasts and that mid-density sites experience the highest number of summer days, totalling 22, compared to 19-20 in the city centre. The highest amount of moderate heat stress and higher (PET > 29°C) was observed in FRLAND (26,3%) compared to 13-19% at rural sites. Also more tropical nights were observed at inner city sites with 5-6, compared to 3 at outer, primarily suburban sites. Remote and rural sites reported no tropical nights.

Over the full annual cycle and the entire network, the number of tropical nights ranged between 0 (rural) and 29 (inner city) per year. The highest number of summer days per year was recorded in industrial and suburban areas (up to 101) compared to 84-97 days in the city centre and 62-90 days at rural sites. The average annual air temperatures reveal a distinct long-term heat island with an annual mean temperature up to 14.0°C in the city centre, and 11.6°C - 12.7°C at rural sites of same elevation.

These results highlight the benefit of continued monitoring for real-time assessments, efficient identification of hot-spots for climate adaptation strategies, and model evaluation and to improve our understanding of urban heat islands and human thermal comfort patterns. In addition, an outreach platform and mobile app (uniWeather^{TM}) have been developed to provide end-users and the public with free access to real-time data and interpretation following FAIR principles.