Exposition to combined stress in public urban spaces – An approach to modeling, analyzing and visualizing of combined exposition to stress resulting from noise, heat and particulate matter

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1 INTRODUCTION

Nowadays the majority of the world´s population lives in urban spaces (United Nations, 2012). In the context of urban planning and urban development divergent demands of the residents of the living space "city" have to be taken into account.
Planning, implementation and maintenance of such areas require an integrative method which has been only partly considered to date (Nasir et al., 2012; Vlachokostas et al., 2011). Particularly, the consideration of situations with the exposition of individuals to combined stresses presents an important challenge. Additional adverse coupling effects which result from a combination of stress due to heat, noise and particulate matter (PM) cannot be identified without concurrently regarding all involved factors.

2 RESEARCH DESIGN

2.1 Methodology

Facing the issue of an integrative method the aim of the project is the consideration of situations with combined stress in a measurement and modeling chain. Ultimately, it is intended to derive combined stress indices and to eventually visualize them in a virtual environment. Besides the thermal component, investigated in a detached preliminary study at the investigation site "Elisenbrunnen" (Maras et al. 2013), air quality, acoustical and acceptance relevant factors are considered and integrated. It is examined which combined stresses may arise for urban residents in various designed urban open spaces also with regard to climate change projections (IPCC, 2013). Thus conceptual alternatives with low overall burden can be evaluated. In contrast to previous approaches this study focuses on stresses diversified by user profiles, gender and age in order to transfer results into specific alternatives in urban development and planning with respect to user groups.

2.2 Experimental setup

As a generic public space in Germany, a first measurement campaign was carried out in the city of Aachen from January 31st to February 21st 2014 representing a typical wintertime situation in

Germany. A similar campaign is scheduled for summer 2014 at the same location. The investigation site "Elisenbrunnen" spans an area of about 0.02 km^2 and is characterized by a well-attended inner city park, enclosed with buildings generally comprised of 4-5 floors. One of the most frequented roads by public transport buses in Aachen including a main bus stop leads through the investigation area in the Southeast. This road is inaccessible for individual private vehicles. A pedestrian road faces the park in the Northwest. Further roads surrounding the study area are generally accessible by all motor vehicles but remain sparsely busy (see figure 1).

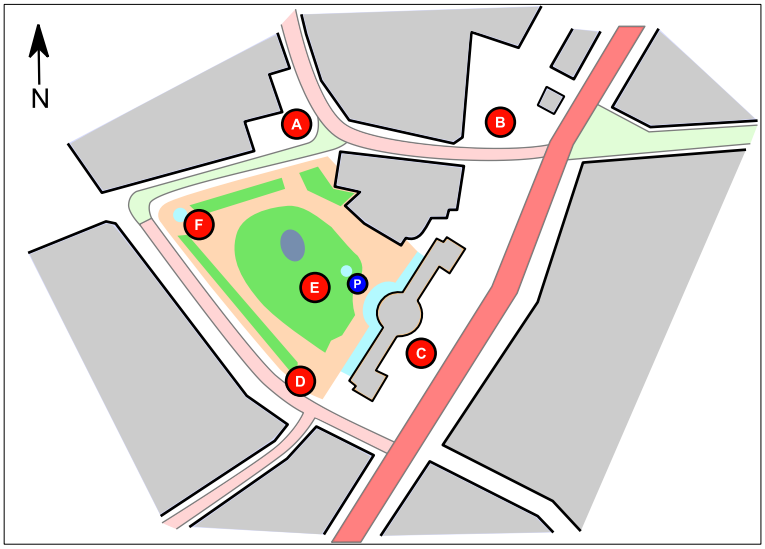

Figure 1: Layout of the investigation site including the permanent measurement location (blue dot) and the mobile measurement and survey locations (red dots). Built-up areas are given in grey.

The experimental design included continued measurements of wind with a 3-d sonic anemometer as well as air temperature and air humidity in the center of the park at 3.5 m above ground level (agl). Furthermore, mobile atmospheric measurements at the bio-meteorological standard height of 1.1 m agl, i.e. 3-d infrared and solar radiation, air temperature, radiation temperature, wind (2-d sonic anemometer), and PM (at 1.4 m agl) were carried out at five different sites inside the park. Atmospheric values are compared to each other and to a permanent urban weather station and are statistically analyzed. In addition, the measured data provides boundary conditions for micrometeorological simulations (see 2.3).

Due to the highly variant sound field not only in time but also in space, a receptor-oriented noise measurement during the interviews of urban park users has been chosen (Brown and Lam, 1987). Therefore, audio recordings were taken using an omnidirectional microphone and a dummy head for capturing binaural sound. At a later stage classical statistical analysis (i.e. A-weighted sound pressure level), psychoacoustic parameters (i.e. loudness) and the subjective impressions of the pedestrians will be correlated following the approach of Kang (2006). Experimental noise signals will mainly be used as a reference for auralization of virtual cities with the aim to ensure binaural reproduction quality through listening tests.

In addition to physical measurements an empirical study collecting qualitative and quantitative data (assessment of perception and sensation by urban park users) was conducted. Among others, the questionnaire consisted of demographic data, health and stress levels as well as perception and sensation of meteorological and acoustical factors. In the study 152 participants (47 % male, 53 % female) took part with an average age of 38 years (SD = 20; age range 11-95 years). In the further process, data will be evaluated with respect to deviation of assessment of park users and to divergence of meteorological and acoustical parameters (physical point of view) due to different

places, respectively. Moreover, it will be analyzed how far perception of places and actual measurements (meteorological and acoustical) do correlate. Beyond, qualitative data will be evaluated in regard to participants' demands. Ideas aiming at improvements of the park will be considered within the development of future urban planning alternatives.
Comparative measurement campaigns are planned to be accomplished additionally in Münster and Berlin. The city of Münster differs only in structure whereas the latter distinguishes in size and structure.

2.3 Modeling

Data will be used to calibrate and validate an atmospheric modeling chain in addition to a noise level model.
The atmospheric modeling will include macro- and micrometeorological simulations as well as air quality simulations, i.e. high resolved spatial PM distributions. The numerical model referred to as ENVI-met (Bruse and Fleer, 1998) will be used to obtain micro-scale information on turbulent energy transport and the aerosol dilution, respectively. Moreover, ENVI-met provides detailed spatial resolution of thermal comfort by using the predicted mean vote (PMV), as shown for the study area (see figure 2) in Maras et al. (2013).
On the one hand atmospheric inflow boundary conditions for ENVI-met will be provided by measured data and on the other hand WRF-model results will feed the micro scale model for the investigation of presumably occurring future extremes.

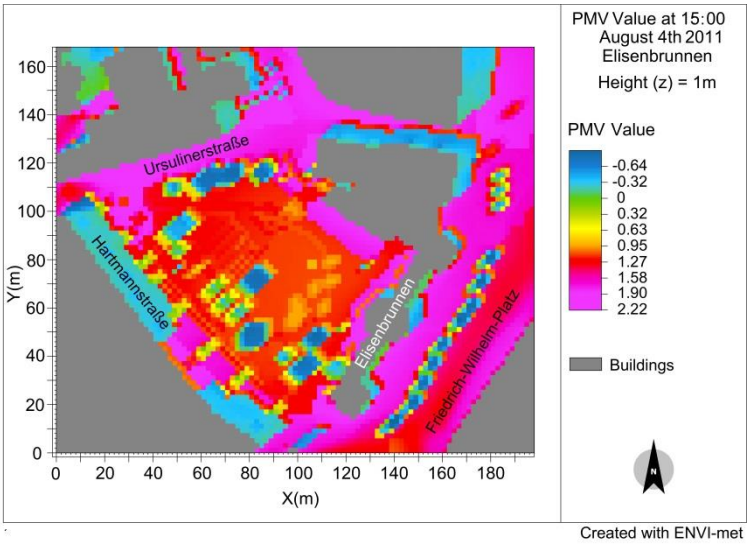

Figure 2: Simulated PMV values for the study area "Elisenbrunnen" at 15:00 on August 4th 2011 (Maras et al. 2013).

To specify further static boundary conditions, a detailed vegetation survey and mapping were accomplished to measure the height and shape of vegetation, the grade of soil sealing as well as the presence of plant species within the several different structural components of the investigation site. In addition, a 3-d city model is developed. Within ENVI-met buildings are set up as non-porous grid cells and façade property dependent heat transfer coefficients.
In order to provide detailed information on the test site, this city quarter is represented as a semantic data model. The model is used as basis for later simulations and visualization of the investigated processes and phenomena. To achieve a unified data model consisting of the

buildings and their environment, a method considering the import of Building Information Modeling (BIM) and Industry Foundation Classes (IFC) data models of the buildings into a City GML environment is followed (van Berlo and de Laat, 2011; Gröger and Plümer, 2012). A workflow proposed by Gurevich and Sachs (2014) demonstrates the potentials of using BIM models in CAVE visualization to explore the subjective perception of participants for the solution of construction problems. In this project however, the first objective is the extension of the semantics of the unified city model for a comprehensive data representation of the indicators of all domains and second, the visualization of the extended, customized data model to achieve a maximally realistic experience in the CAVE with regard to the participant's perception.
The evaluation and gathering of model results will exemplarily provide information about the distribution and intensity of stresses regarding different types of built-up areas, user profiles and topographic positioning.
The visualization allows the integration of data in the process of planning and consideration of alternatives for urban development, which will subsequently be verified with micrometeorological simulations.

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