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A new wearable monitoring system for investigating pedestrians' environmental conditions: Development of the experimental tool and start-up findings

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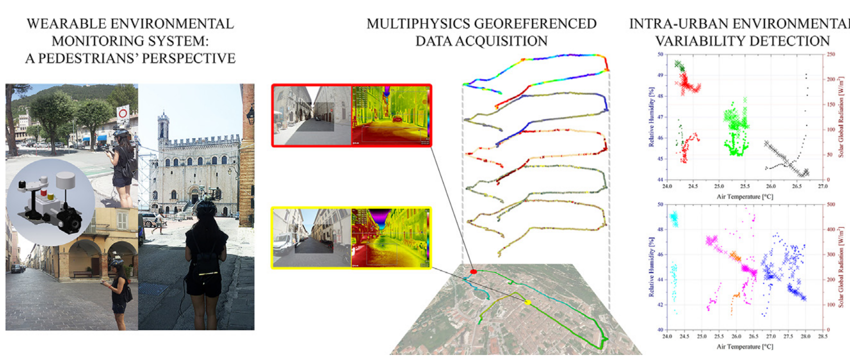
HIGHLIGHTS

- Outdoor microclimate continuous monitoring in urban areas is carried out in summer.
- Wearable monitoring is used to study pedestrians' exposure to urban environment.
- Microclimate, air quality, IR/VIS images field study is performed.
- Various intra-urban environmental configurations are shown by continuous monitoring.
- Novel wearable system identifies citizens' resilience and promising mitigation.

GRAPHICAL ABSTRACT



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ABSTRACT

Urban population is predicted to increase rapidly and massively in the next decades, by producing also the exacerbation of urban scale climate change imputable to anthropogenic actions, such as urban heat island. In this view, urban pedestrians assume a key role in determining city livability in dense built environments, typically much more polluted than suburban or rural areas. Despite that, urban heat island experimental studies are pretty focused on data collected by means of permanent microclimate stations for environmental monitoring, also coupled with satellite measurements or mobile stations equipped over transportation media. This work deals with the development, experimental startup with field test and critical data analysis of a brand new wearable system for microclimate and air quality investigation, just developed with the purpose to characterize livability environmental conditions which affect urban population wellbeing. To this aim, the experimental tool definition and the first field test are carried out in a historical city centre in Italy, where cluster analysis is performed in order to also identify the role of urban design in affecting key microclimate parameters such as air temperature, solar radiation, daylight, air pollution and pedestrian thermal comfort in general. The analysis showed that very site-specific environmental conditions may be detected while several environmental spheres are investigated by the novel wearable system in summer conditions.

1. Introduction and research background

Urban population is in rapid and continuous growth all over the world and especially in developing countries. The United Nations

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Department of Economic and Social Affairs estimated that 54.5% of the world population was living in urban settlements in 2016 and by 2030 this percentage is predicted to rapidly rise up to 60% (United Nations, Department of Economic and Social Affairs, Population Division, 2016). The chaotic urbanization process led to increasing urban areas extent which implies progressive land-use and land-cover modification contributing to modify the energy balance in cities. This phenomenon affects urban thermal environment with key consequences on the exacerbation of Urban Heat Island (UHI), consisting of the well-known higher air temperatures detected within an urban context with respect to its rural surroundings (Howard, 1833; Oke, 1973; Arnfield, 2003). UHI has several negative consequences on (i) human health and thermal comfort of pedestrians and, more in general, of urban citizens (Kovats and Ebi, 2016), (ii) urban air quality altering the city photochemistry (Serrat et al., 2006) and (iii) building stock energy consumption in terms of heating and cooling requirements (Akbari et al., 2001). Moreover, synergies between UHI and heatwaves were demonstrated by Founda and Santamouris by examining five heat-wave events during summer 2012 in Athens (Greece) (Founda and Santamouris, 2017). Macintyre et al. also demonstrated the key correlation between UHI and heat wave by also showing that heat exposure for urban populations vary across urbanised areas characterized by spatial variations in infrastructures and urban design choices (Macintyre et al., 2018). In fact, they investigated several risk factors which may make population more vulnerable during periods of hot weather. An analysis of the spatial distribution of multiple risk factors across a region may reveal co-location of such factors, and identify places when strategies to mitigate heat risk might be most effective. Therefore, all the negative implications of UHI are going to be exacerbated in the next future since such extreme weather events have been predicted to be more intense and more frequent due to climate change (Meehl and Tebaldi, 2004).

Nevertheless, urban landscapes are strongly characterized by a high level of heterogeneity and complex morphology. This is responsible for a diversification of microclimate conditions even within the same city and not only by comparing urban conditions and rural surroundings. Jonsson detected an intra-urban temperature difference of the same range of the urban-rural differences in the city of Gaborone, Botswana (Jonsson, 2004). Non-negligible temperature differences, i.e. up to 5 °C, were also detected among different areas of Wien, Austria by Mahdavi et al. (Vuckovic et al., 2017). Moreover, the study highlighted the correlation between the building thermal performance and the location-specific microclimate conditions, founding out a mean annual heating load variation up to 16.1 kWh/m^2 per year across the analysed locations in Wien, Austria.

In this view, the understanding of intra-urban microclimate variation and how much this is determined by the site-specific structure of the built environment becomes fundamental to identify suitable mitigation actions aiming to improve the quality of the total urban environment from the human perspective of urban citizens, (Or et al., 2017; Gunawardena et al., 2017) and also to better analyse the building stocks energy consumptions (Pisello et al., 2015). For this purpose, high-spatial-resolution climate data are required in order to investigate microclimate variation at small-scale and from a pedestrian perspective, which is rarely reached by classic field campaigns. The experimental methodologies usually implemented to guarantee a reliable precision microclimate level include: (i) remote sensing, (ii) collection of data through a network of permanent weather stations and (iii) observational mobile transects over vehicles (Alquarashi and Kumar, 2017; Voogt and Oke, 2003; Estoque et al., 2017; Morabito et al., 2016; Weng, 2012; Song et al., 2017; dos Santos et al., 2017; Geiger et al., 2003; Paolini et al., 2017; Cui et al., 2017; van Hove et al., 2015; Hart and Sailor, 2009; Parace et al., 2016; Klemas, 2015). Such experimental methods can be implemented by themselves or mutually combined in order to reach higher precision level in the analysis.

Researches focused on satellite imagery are aimed at quantifying land-use and land-cover changes due to urbanization (Alquarashi and Kumar, 2017) or evaluating the urban thermal pattern obtaining land surface temperatures from remotely sensed images (Voogt and Oke, 2003). Estoque et al. demonstrate the strong correlation among the land surface temperature and impervious-green urban surface patches in three metropolitan regions of the Southeast Asia, i.e. Bangkok, Jakarta, and Manila, by means of Landsat-8 OLI/TIRS data (Estoque et al., 2017). In Italy, a strong correlation among the different urban morphologies and land surface temperature variation has been pointed out by Morabito et al. using MODIS remote sensing data (Morabito et al., 2016). These typologies of urban environment investigation are usually coupled with measurements at ground level taken by permanent or temporary weather stations installed in strategic positions, that in some cases, are also used to validate the remote sensing esteemed temperatures (Weng, 2012; Song et al., 2017). A methodology proposed by dos Santos et al. (dos Santos et al., 2017) aims at determining spatial and temporal distribution of the UHI by integrating remote sensing imagery and meteorological data collected by a permanent meteorological station is. Nevertheless, a limitation of remote sensing technique consists in a not accurate representation of site-specific ground surface characteristics, when recording just building roof conditions in some regions (Geiger et al., 2003).

More commonly, weather stations networks are used for determining the spatial variability within an urban context (Paolini et al., 2017). The availability of fixed or temporary non-movable stations provides weather data acquisition for long-time periods allowing both reliable site-specific temporal characterization of the urban heat island intensity within cities (Cui et al., 2017; van Hove et al., 2015). On the other hand, such networks are usually limited in number of monitoring spots and they present a sparse and location-dependent distribution, which therefore cannot interpret dynamic place-to-place variation of microclimate key conditions affecting outdoor comfort and environmental wellbeing conditions affecting pedestrians at ground level. Moreover, the sensors placed in each weather station are often limited in number due to the costs of such devices and the massive maintenance effort they require.

Finally, some researches use mobile units to record weather parameters along specific transects (Hart and Sailor, 2009; Parace et al., 2016). Differently from the previous descripted methodology, in this case the data acquisition should refer to shorter temporal intervals. This is fundamental to minimize evaluation errors due to mixing of temporal and spatial variation, since the collected parameters change during the course of the mobile monitoring campaign. Generally, such mobile units are motorized vehicles, e.g. cars etc., and therefore the analysis of the urban landscape is restricted just to roadways and parking areas, and its reliability is also affected by the same transportation vehicle which perturbates its surrounding turbulence, air velocity field and possible self-shading effects.

Based on such background, this work presents a new developed device consisting of a miniaturized wearable multiphysics weather station which can be easily used to collect weather and other microclimate parameters (air pollution, thermal, solar and other microclimate-related parameters) along cities transects and other environments, even suitable for monitoring those places that are not accessible for commonly used transportation vehicles. In fact, the developed device can be settled either on helmet or a backpack (pedestrian view) or on a UAV (Klemas, 2015; Rossi and Brunelli, 2016) due to its characteristics of light-weight and small-size. The purposes of the work are presented more in detail in Section 2, while the new monitoring system and the startup field experiment is presented within the methodology section, i.e. Section 3.

Discussion of the results obtained during a monitoring campaign conducted in summer conditions in an Italian city (i.e. Gubbio) is presented in Section 4. Finally, conclusions including future developments concerning further monitoring activities and the data post-process innovative techniques, are dealt with in the end of the paper, where also the key features of the system are highlighted in terms of its potentiality to characterize the total environment perspective of pedestrians.