Use of a mobile platform for assessing urban heat stress in Rotterdam

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Abstract

In this study, an assessment of the intensity of the urban heat island (UHI) in Rotterdam was carried out using an innovative mobile bio-meteorological measuring platform mounted on a cargo bicycle. The goal was to assess whether or not heat stress is currently or likely to become a critical issue. Physiological equivalent temperatures were calculated directly from the measurements. Preliminary results show how effective urban parks and greenery are in reducing the UHI. The maximum UHI was about 7 K warmer than the rural area, whereas greener urban configurations were under 3 K warmer. City parks show marked cooling effects during daytime. The preliminary results clearly demonstrate the presence of a considerable UHI in Rotterdam, which is expected to be found in other Dutch cities, and confirms the important role of green spaces in mitigating urban heat stress.

1. Introduction

The majority of the world's population now live in urban environments. The average temperature of built-up areas is higher than the surrounding rural area, which enhances heat stress, and is called the Urban Heat Island (UHI) effect (Oke, 2006). Because The Netherlands has a mild Cfb climate and is situated close to the sea, it was never considered an issue for urban planning even though the level of urbanization began to increase rapidly. Currently the built-up area is over 15% of the total land area and increasing. Recent heat waves of the year 2003 and 2006 caused an excess in mortality in The Netherlands of between 1400 and 2200 people. Climate projections predict that heat waves in The Netherlands will likely become more frequent in the next decades, which will compound the environmental stresses of urban life and lifestyles. However, information regarding UHI in Dutch cities is completely lacking, both from observational and model perspectives, which hampers the design of suitable adaptation and heat mitigation strategies. Even moderate heat waves should not be underestimated for a maritime climate. The reason is that the population has no time to acclimatize since adaptation of human thermoregulation usually takes about 1 week.

Spatial planning and urban growth projections using various scenarios all point to a large expansion of urbanized space (Nijs et al., 2002). The scenarios of the Dutch National Nature Outlook study (MNP, 2002) which are based on various IPCC-scenarios, also supports this. Comparing these scenarios to the current situation (2010), urban growth seems to follow the 'Global Market' scenario. This scenario suggests strong population growth, free trade, strong technological developments, limited role of government, strong decrease in agricultural land and a luxury consumption pattern. The most important land use changes in The Netherlands over the last 10 years are related to the increase of urban and nature reserve lands at the expense of agricultural land (Hazeu, 2006), and mixing of different land-use types in both urban and rural areas (Ritsema et al., 2006. The Land Use Scanner tool (LUS) was used to simulate how The Netherlands land use would look like in 2040. The LUS is a GIS-based logit model that simulates future land use (Hilferink and Rietveld, 1999) and has been used for various policy-related research projects.

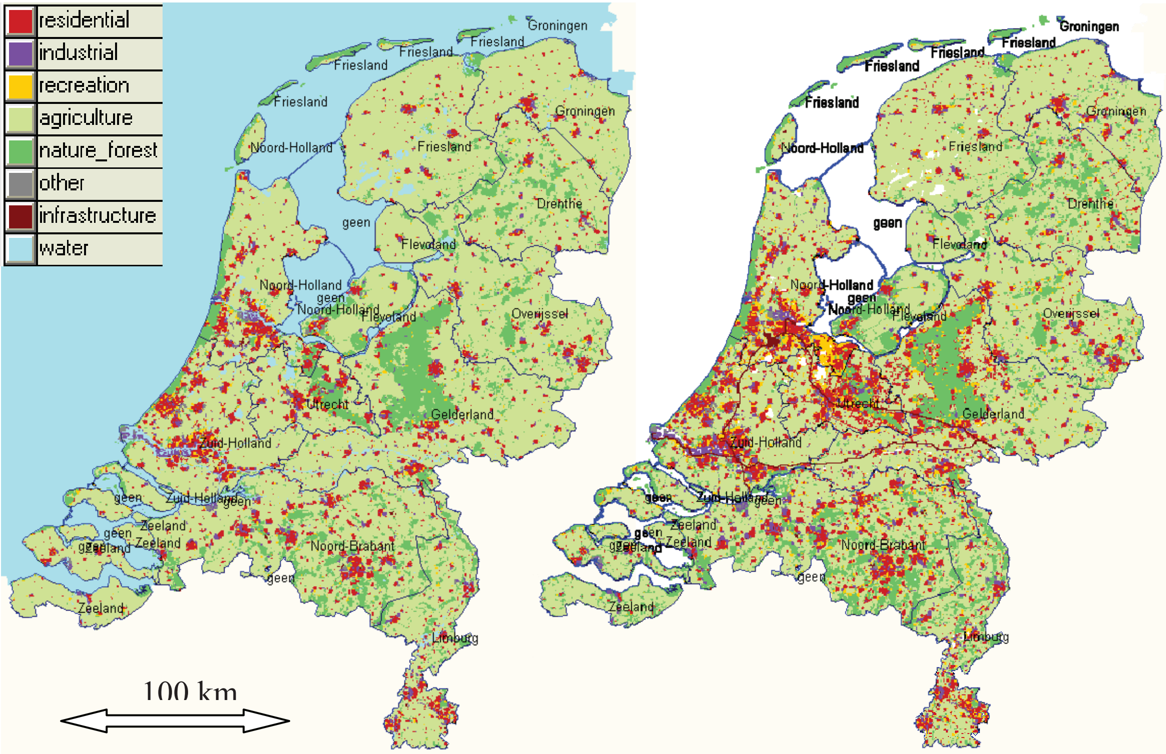

Fig. 1: Land use scenario, left side year 2000, right side year 2040

The 'Global Market' scenario simulation estimates 20 % urbanization in 2040 (Fig. 1). The definition of urban space also includes infrastructure and industry but there are some differences in the definition and the Dutch planning office includes, for example, urban greenery and urban infrastructure but not external infrastructure. The impact of infrastructure on surface heating is significant and therefore should not be excluded from such analyses.

This study examines the extent of the urban heat island effect (UHI) of the city of Rotterdam, which is part of the largest urban conglomeration of The Netherlands with more than 1.2 million inhabitants on 870 km^2.

2. Materials and methods

Traverse measurements were performed in Rotterdam using two cargo bicycles as a mobile platform, equipped with innovative instruments to quantify the micro-meteorological conditions inside urban canyons. The cargo bicycles greatly facilitated data acquisition through the narrow streets and urban canyons of pedestrian areas. The bicycles were equipped with a shielded thermometer, a humidity sensor, a 2-dimensional sonic anemometer and 12 radiation sensors to measure solar radiation and thermal infrared radiation exchange from six directions (Fig. 2). Wind speed measurements were corrected for bicycling speed.

Fig. 2: Mobile biometeorological station mounted on a cargo bicycle

The data were recorded at 1 Hz and combined with concurrent readings from a GPS device. The instruments were powered by a solar panel mounted on the baggage carrier. Measurements were performed along two previously determined routes through a number of characteristic urban districts, including an industrial area, an older residential area, a city park and a harbour area. The routes were photographed at fixed intervals from 0.5 m above the ground with a fisheye lens pointing upwards. The observations were carried out during three 2 h time intervals on 6 August 2009. This was a warm day with maximum air temperatures of about 30°C. Data from the traverse measurements were compared with recordings from a nearby synoptic weather station outside the urban area. Fig. 2 shows a detailed view of the front of the bicycle.

A very important factor in the human energy balance is the mean radiant temperature (T_{MRT}), and this can be calculated directly from the 12 radiation sensors and correlates very well with perceived human comfort (Matzarakis et al., 2007) (Eq. 1).

$$T_{MRT} = \sqrt[4]{\frac{Q_a}{\varepsilon\sigma}} - 273.15 \qquad (1)$$

Where Q_a is the total shortwave and thermal radiation absorbed by the human body (W m^{-2}), ε is the thermal emissivity (-) and σ is the Stefan Boltzmann constant (W m^{-2} K^{-4}). Directional dependant weighing factors and shortwave radiation absorption coefficients need to be considered for calculating radiation load on a human.

The advantage of these extensive measurements are that the human micro-climate can be quantified using physiologically relevant indices that are much more accurate than indices derived from standard weather station data. Examples include the physiologically equivalent temperature (PET) (Höppe and Mayer 1987) or predicted mean vote (PMV) (Fanger, 1972). PET is defined as the physiological equivalent temperature at any given place, and thus complex outdoor microclimates can be compared with a climate chamber with temperature of air, floor, walls and ceiling at PET temperature (wind speed 0.1 m/s and relative humidity of 50%). The higher accuracy for human micro-climate indices derived from such a mobile station is mainly related to its ability to measure omnidirectional radiative fluxes. These flux measurements determine T_{MRT}, which is the most important meteorological parameter for calculating the human energy balance under summer conditions (Clark and Edholm, 1985).

3. Preliminary results and discussion

An initial analysis shows that the UHI is very large after sunset with an air temperature difference of more than 8 K between city center and rural environment (grassland). An interesting observation was an industrial zone with dark flat roofs. This area appears to have the hottest surface temperature of all urban areas in Landsat thermal infrared images. However the bicycle measurements did not find this area hotter than the city center, especially not during the evening hours. This might be related to the low thermal inertia of the flat roofs. The UHI is strongest after sunset and gradually declines during the night. Air temperature remains higher than the rural area due to the slow release of solar heat storage originating from daytime solar radiative forcing.

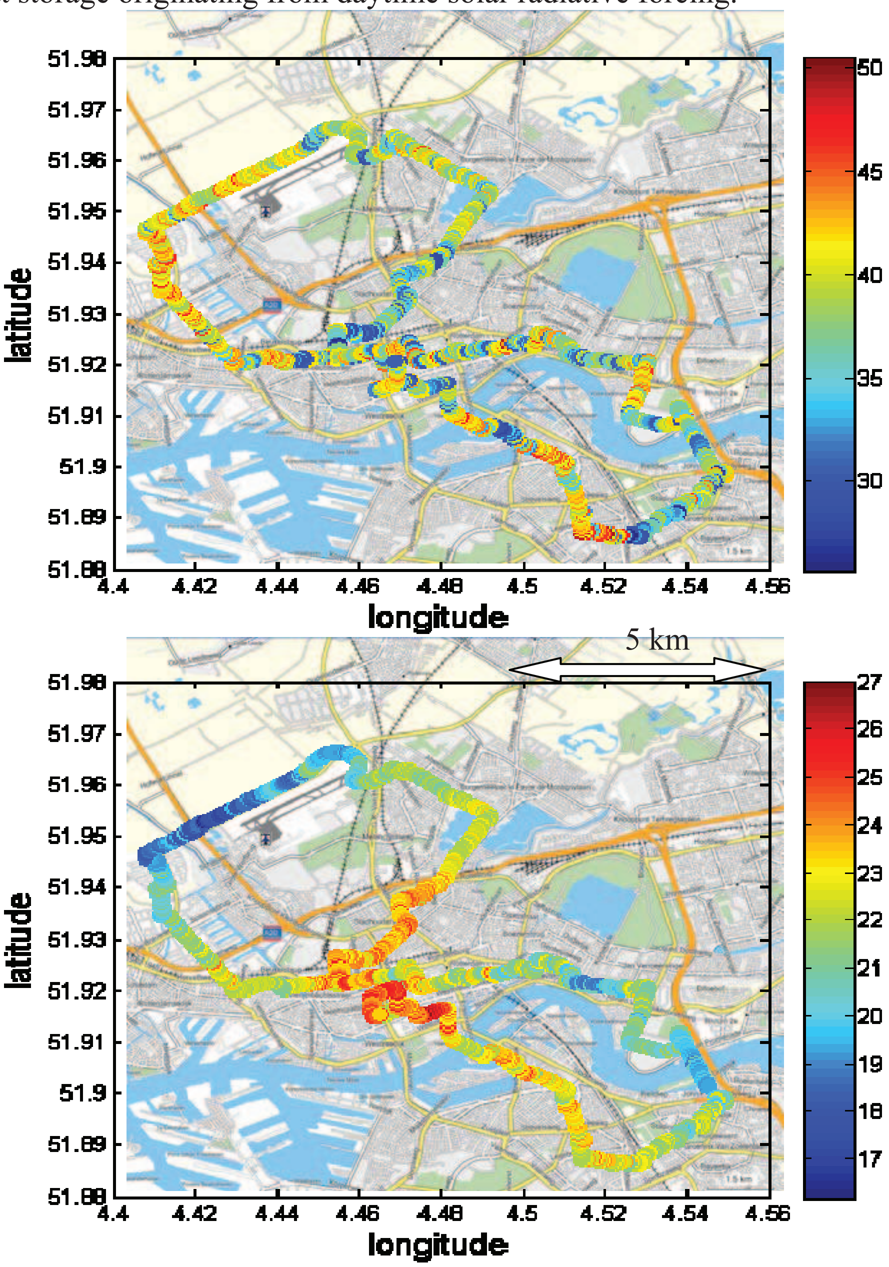

Fig. 3: Traverse measurements of Rotterdam, PET, Upper panel 14:00-16:00 h. lower panel 22:00 – 24:00 h (Central European Time)

PET (Fig. 3) could be easily calculated because of the direct measurements of all the radiation components. Rayman software was used to compute PET without the need to calculate complex city canyon radiation distribution because T_{MRT} was measured on the bicycle (Matzarakis et al., 2007). The measurements show some interesting features. A park in the southeast side was the coldest spot during daytime whereas a neighborhood just east of the city center was the coolest urban spot during the evening hours. Both routes were documented using fish-eye photography.
An isolated tree in an urban canyon does not seem to have much influence on PET during evening hours (Matzarakis et al., 2007). However the bicycle data shows that a neighborhood with scattered trees does have a marked impact on air temperature during evening hours. On the other hand, a nearby park shows the opposite, which may be related to the closed canopy cover. This is also evident in the calculated PET.

4. Concluding remarks

In a changing climate and with future urban space projection scenarios showing Dutch urban density increasing from 14% in 2000 to 20% by the year 2040, it is likely that the UHI impact will become much more serious. The UHI effect may also accelerate even faster because many isolated and growing urban clusters will start to influence each other, an issue worthy of further investigation.
The presented biometeorological measurements using a cargo bicycle proved to be a valuable tool for investigating urban biometeorological conditions. While traversing the city of Rotterdam PET ranged from 25 to over 50 °C during a hot afternoon (6 August 2009). The neighborhood with the lowest PET during daytime and evening hours appears to be an urban configuration with low buildings and extensive greenery.

Acknowledgements
This research was part of the project “Heat stress in the city of Rotterdam” (HSRR05) funded by the first phase of the Knowledge for Climate Program and the municipality of Rotterdam. We also like to thank the students Joel Schröter, Marina Sterk and Suzanne Visser for their support on the measurement days.

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