Available online at www.sciencedirect.com
ScienceDirect
Building and Environment 43 (2008) 7–17
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

A fieldwork study on the diurnal changes of urban microclimate in four types of ground cover and urban heat island of Nanjing, China

Liangmei Huang[a,b], Jianlong Li[a,*], Dehua Zhao[a], Jiyu Zhu[b]

[a]School of Life Science, Nanjing University, Nanjing 210093, China
[b]Guangxi Forestry Research Institute, Nanning 530001, China

Received 7 March 2006; received in revised form 16 November 2006; accepted 30 November 2006

Abstract

Records of the past years showed that the climate of built-up regions differs significantly from rural regions and one of the most obvious and important modifying effects of urbanization on local climate is the urban heat island (UHI). In this paper, four types of land cover, namely urban bare concrete cover, urban woods or the shade of trees, urban water areas and urban lawn, were selected to study their microclimate, and the UHI was also analyzed using air temperature data measured at four fixed observation spots in Nanjing, China, during hot weather from July to September, 2005. Dry and wet bulb temperature data were obtained by whirling psychrometers, and wind speed data by cup anemometers. Our observed data focused on the detailed statistical analysis of the microclimate variation in the four types of land cover during the whole day. The results showed that: (1) the microclimate of these four types of land cover had significant differences among different observation sites. In general, the air temperature of these four types of land cover complied with the order during daytime: bare concrete cover > lawn > water areas > woods or the shade of trees, with reversed order during nighttime when the air temperature of the lawn became the lowest. Compared with the bare concrete cover, the other three types of land cover showed the effect of dropping air temperature ranging between 0.2 and 2.9 °C. There were some instant dynamic characteristics in detailed temporal series among these four types of cover in the different observation sites. (2) The UHI effect could be detected obviously by the air temperature difference between the urban center area and the rural area. The average UHI intensity during the monitoring period was between 0.5 and 3.5 °C; however, there were also significant day-to-day variations. A strong UHI effect usually occurred around midnight; while about 2–3 h after sunrise the UHI began to decrease till midday time; and during 13:00–15:00, the UHI effect had a sudden increase and then decreased again; after sunset, a peak UHI effect was frequently observed during 18:00–21:00. (3) Finally, by means of the standard deviation (SD), this paper provides a concise and comprehensive understanding for the temporal and spatial microclimatic dynamics of these four kinds of urban cover in the four observation sites. Air temperature at the height of 1.5 m in Nanjing showed that the nocturnally horizontal temperature gradient was somewhat different from that reported in other large cities, and a marked heterogeneity in a smaller ground cover scale could be detected from the microclimatic spatial pattern. There is no doubt that the analysis of these four types of land cover presents the insight into possible countermeasures to decrease the high air temperature in hot summers, and is relevant to the urban planning redevelopment.

Keyword: Urban ground cover types; Site specific effect; Reference points; Data normalization

1. Introduction

Human settlements modify the materials, the structure and the energy balance of the surface of the Earth and the composition of the atmosphere compared with the surrounding 'natural' terrains, although they also suffer from some effects of human economy e.g., agriculture, forestry. These artificial factors determine a distinct local climate in the cities, which is the so-called urban climate [1–4]. The damages on the natural and built-up environments, caused by the speculative use of urban spaces, have been taking their most serious form, and, from the climatic point of view, have been harmful to the cities and their residents, such as excessive heat storage and high concentration of air pollution. In order to prevent these

*Corresponding author. Tel./fax: +86 25 83592715.
E-mail address: jlli2008@nju.edu.cn (J. Li).

0360-1323/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2006.11.025

damages and create optimum bioclimatic conditions, studies on the urban climate, the urban heat island (UHI) and urban air pollution are stimulated not only by the necessity to gain knowledge of numerous secondary effects of the excessive urbanization but also by very practical needs of town planning.

Studies of individuality of the urban climate have been conducted for over 150 years, as long ago as that it was observed in big cities of temperate latitudes (London, Paris) [5]. Since then, much research has been done on various interesting and practical aspects of urban climatic phenomena by means of different measurement tools and methodology, and the UHI features have also been clearly demonstrated [2,6–23]. Researchers have mainly paid attention to the spatial and temporal distribution, cause and effect as well as prediction model of the urban climate, the UHI and air pollution, and failed to take climatic considerations of urban design into account; therefore, data provided by climate researchers have a low impact on the urban planning process, and do not always meet the demands of urban planners and architects. While rapid changes in microclimate generated by different urban land cover influence the comfort and health of the inhabitants as well as energy consumption and air quality, therefore, it is important to understand the causes of air temperature variation in different land use areas.

A few studies have measured the temperature distribution on the exterior of a single building [12,24] and over two representative buildings having different construction characteristics both in the summer and the winter [25]. A study of a selected urban area of central city and comprehensive analysis of various urban objects over a 24-h period had been also conducted in Tel-Aviv using an infrared video radiometer [26]. However, for a diversity of urban ground cover and weather conditions, these studies were confronted with problems of spatial and temporal data substitution due to the lack of a long data record and poor spatial sites. But high temporal and spatial resolution and the use of concurrent ground truth data are necessary for accurate measurement [27]. From a climatological perspective, the UHI and its negative environmental influence are also pronounced during the hot season. Experiments on diurnal range basis during a calm winter day, which demonstrated the most pronounced radiant temperature differences between diverse urban coverage at microscale level, have been carried out in the cities Goteborg, Hokkaido and Tel-Aviv [10,26,28]. However, few field experiments were carried out in the hot season; therefore, it is important to carry out simultaneous field experiments at different sites for monitoring the thermal pattern of the urban land cover more accurately in the hot season.

In an attempt to address this important issue, this paper examines the effects of four different types of urban land cover on air temperature variations between day and night, different months and different observation weather situations at four observation sites in Nanjing, China, during the hot summer period. We presumed that there would be a most representative type of ground cover at each observation site. Based on the detailed analysis of the variation of these samples of data measured from the sites, this most representative type of ground cover would be classified. This paper covered the following aspects:

- An analysis of the air temperature differences from different types of ground cover.
- An analysis of the temperature differences from the different observation sites.
- A comprehensive and concise understanding of the deviation of the air temperature in temporal and spatial series.
- A discussion of the application of these results in urban planning.

2. The study area: the city of Nanjing

Nanjing is one of the six ancient capitals of China, and is situated on the south bank of the lower reaches of the Yangtze River. Together with the other two cities of Chongqing and Wuhan along the Yangtze River, Nanjing is also famous as 'the city of the chimney place' for its hot climate with maximum summer temperature of 40 °C. It is located at 32°03'N in the north-subtropical climatic zone with well-defined seasons and a mean annual temperature of 15 °C. Rainfall averages 1033 mm per annum, occurring mainly in summer. The zonal natural vegetation is a mixed broadleaf evergreen and deciduous forest. Sampling survey of urban trees yielded an evergreen:deciduous trees ratio of about 1:3, and the top three species were *Platanus acerifolia*, *Juniperus chinensis* and *Ligustrum lucidum* [29]. The city's varied topography comprises mountains, low hills, low terraces, plains and rivers (Fig. 1). Two rivers and two lakes define the drainage system. The Yangtze River runs in the northwest, and the Qinhuai River runs southeast to northwest through the city to join Yangtze, it bifurcates into a cluster of tributaries that spread in the south city. Xuanwu Lake (3.7 km^2) west of Purple Mountain and Muchou Lake (0.37 km^2) west of the city wall have been developed into municipal parks. Fringe mountains surround the city, extending as low hills into built-up areas. The Purple Mountain at its eastern fringe, rising to 448 m, has the largest green cover of 29.7 km^2 of semi-natural forest. In the southeast and southwest, there are green wedges of farmland which break up the otherwise monotonously contiguous urban developments. In the south, there is Yuhua Hill providing extensive green spaces for the nearby densely populated old downtown, and it is physically segregated from the inner city by the railway and the city wall. In the north, Mufu Hill is an elongated belt beside the Yangtze River, which is almost engulfed by the urban area except for the narrow riverbank which serves as a corridor to the extensive countryside beyond the city. The extensive green space penetrating into