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Simulation of Urban Microclimates in Tropical Metropolis' Maracanã/ Rio De Janeiro - A Case Study

Jörg Spangenberg
Institut für Tropentechnologie ITT
University of Applied Sciences Cologne/ Germany
e-mail: joerg_spangenberg@yahoo.com.br

Abstract

In tropical latitudes, the impact of the urban climate is associated to harsher negative impacts on thermal comfort and the energy consumption of buildings then in the cities of the temperate climate zones, due to higher solar radiation income. The formation of the so-called 'urban heat island' in tropical metropolis is also created mainly by the lack of vegetation and by the high solar radiation absorptance of urban surfaces. The addition of city noise, as a result keeping windows shut and the increasing use of air-conditionings degrade the quality of the public open space additionally by anthropogenic waste heat. This case study examines an urban neighbourhood situated in hot and humid tropical climate in Rio de Janeiro/ Brazil. Its microclimate is being modeled with the numerical simulation tool ENVImet. Possibilities of adaptation of the model to local properties and climate are being studied.

Keywords: Bioclimate, microclimate, simulations, urban green, energy efficiency

Introduction

The transformation of the original jungle into a (mostly) concrete urban jungle by men has caused an altered energy balance of the surfaces and thus a modified response of the near-surface climates particularly in tropical cities. This phenomenon is known as urban climate and is associated to many diverse, rather complex and interlinked effects like urban heat islands, thermal discomfort, air pollution, elevated energy consumption for cooling etc. To better understand such complex effects and to be able to analyse them recently simulation tools are gaining ground. In fact problems like the urban climate are far too complex to fully understand them without the aid of such highly sophisticated programs or models respectively. Especially the dynamic, spacial and temporal variations of the microclimates are difficult to grasp and to visualize. Simulations with numerical computer models allow such detailed investigations. Different scenarios can be modeled and simulated, in order to indicate options which are climatically preferable.

Thermal Comfort

Near-surface man-modified climates develop mainly in the street canyon air volume within urban structures at pedestrian height. Thus for microclimate analysis the investigation of the street canyon air volume is of strong interest for the concerns of human thermal comfort. The ground level (street canyons, courtyards, urban greens etc.) is the layer were urban gathering takes place, where recreation areas are located and where the majority of citizens circulates and lingers in the public space. This so-called Urban Canopy Layer is endangered to receive very little natural ventilation in dense urban situations. Yet airflow is (together with shade) the most important improving factor for bioclimatic thermal comfort in the Tropics. Thermal comfort in the street canyons allowing a vivid street life is of special social importance in Brazil because in its cities exists a dangerous tendency towards (climatic and social) separation of whole blocks, introverting against the violence and the thermal discomfort of the public space. The climatic well being of citizens is an important condition for the efficiency and the health of the urban population. Especially the summer period (December to March in the Tropics of the Southern hemisphere) is that of most interest for bioclimatic investigations in the Tropics: Thermal hot stress occurs regularly in the open urban spaces during the summer period, while cold stress develops only rarely in tropical regions. By definition (Köppen) the average air temperature of all months exceeds 18°C in tropical regions.

Energy Consumption

The climatic (as well as acoustic and visual) conditions of the urban outdoor space have additionally important influences on the energy consumption (i.e. for cooling) of indoor spaces. They play therefore also a substantial financial role. Thus in order to instantiate more energy-efficient urban structures again the urban climate must be affected positively. Under tropical conditions as yet in summer a vicious cycle is created by dense urbanization: Constructions of the the so-called, International Style (which was originally developed in temperate climates) are strongly affected by the use of glass and concrete and widely applied in the Tropics although they must be considered climatically unadapted and thus unsustainable. The common materials climatic responses (glasshouse-effect in the interiors and heat retain/ storage of concrete and brick) decrease thermal indoor and outdoor comfort. Increased cooling loads result an increased (and usually inefficient) consumption of electric energy for air conditioning, which is associated to high costs in Brazil. The consuming devices of the electric energy contribute themselves again to anthropogenic waste heat thus heat islands and noise pollution.

Simulation Tool

ENVImet is a numerical, 4-dimensional (three spacial dimensions plus time dimension) microclimate model. ENVImet is an innovative, decision-making tool for urban and landscape planners, architects etc. especially in tropical threshold (and developing) countries, because such investigations can be carried out to relatively low costs. The software is being developed and provided cost-free in the Internet (www.envi-met.com) by Dr. Michael Bruse from the University of Bochum/ Germany. The program simulates the microclimates within urban structures through the solution of the physical basic equations for the wind current, the thermodynamics and the radiation balance of surfaces. It's name (ENVImet) derives from the term **Envi**ronmental **Met**eorology.

ENVImet consists of the following sub-models:

- **the atmosphere model** (wind field, temperature, vapour, humidity, pollutants)
- **the soil model** (temperature and moisture inside the soil, water bodies etc.)
- **the surface model** (fluxes on horizontal and vertical surfaces, pavements, roofs and walls of buildings etc.)
- **the vegetation model** (foliage temperature, heat water and vapour exchange with in-canopy air etc.)

It must be considered that the data implied in the (local) data bases for these sub-models do contain properties of construction materials and plants common in Germany and not yet explicit properties of tropical plants and/ or construction materials in Brazil. This complicates the validation of the program for local tropical/ Brazilian conditions

Considering that such simulations are (almost) as complex as reality also a large CPU (Central Processing Unit) and long calculation periods (common are >24h) are required in order to carry out the simulations. A good understanding of the English language is also needed because the complete program language and that of all applications is through English. The input database of ENVImet demands relatively few parameters and but some of them are highly sophisticated such as LAD (Leaf Area Density of plants), roughness length and soil moisture content. The input data availability usually proves to be the largest difficulty. This results that it is virtually not possible to work with 100% correct input parameters and that unknown parameters must be estimated. Due to this fact and due to inevitable simplifications of the program the results of the simulations must be also regarded as estimations. It has to be remarked that (especially for beginners) there is a huge danger of momentous errors concerning the results during the collection and estimation of data for the input stage.

Case Study Area

The neighbourhood around CEFET (Centro Federal de Educação Tecnológica)/ Petrobras is located a 22° 55’ S and 43° 14’ W in the borough of Maracanã in Rio de Janeiro. The area under investigation has a size of 450m x 225m, which equals a total size of 10.12 ha or roughly 0.1 km². A recent aerial picture (see Photo 1) of the area was used to digitise the model domain. In comparison to a scale drawing the expansion of the outlines of the canopy layer of the tree population are identifiable well. In addition detailed field investigations (vegetation, albedo, ground sealing etc.) were carried out on location. The urban situation was chosen because it suggests a large potential of a great variation of microclimates due to its vertical extension (low and high-rise buildings) and its ground sealing/ vegetation, which varies from highly sealed (Avenida Maracanã) to garden and green courtyard surfaces.

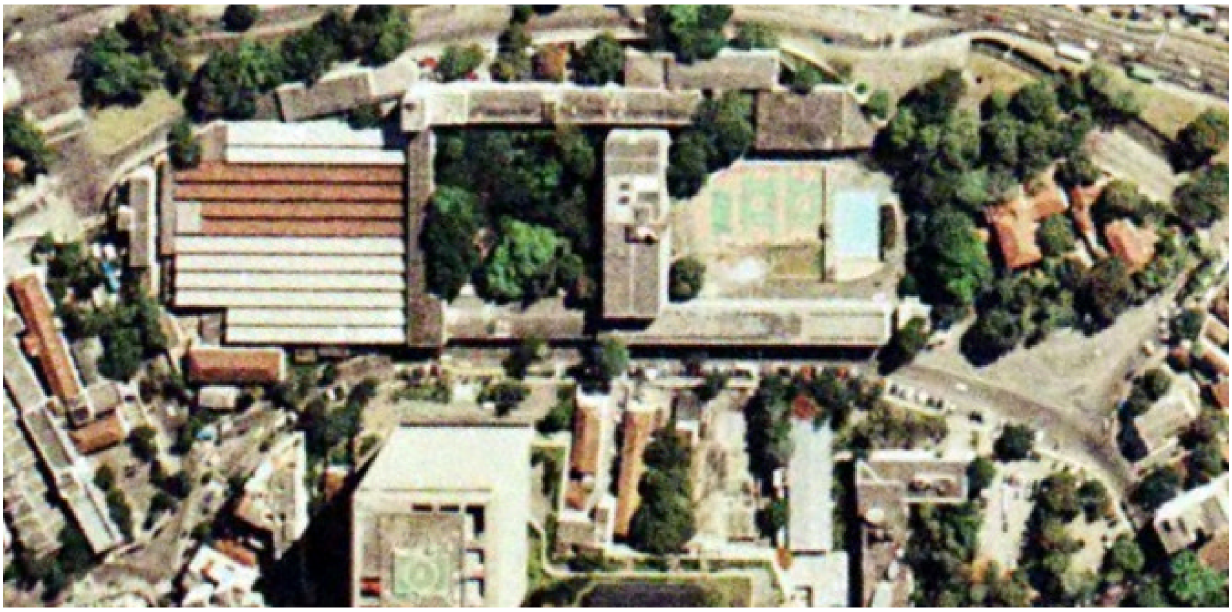

Photo 1: Aerial view of the area under investigation (IPP 1996)

Since local (microclimatic) data from the meteorological station of CEFET unfortunately proved to be useless, similar microclimatic data from the nearby meteorological measuring site of UERJ (Universidade do Estado do Rio de Janeiro) was used to derive an average and an extreme summer day from a reliable series of 10 years using a method by Cartaldi (2004).

Fig. 1: Screenshot of the digitised area under investigation (Layer: buildings, vegetation)

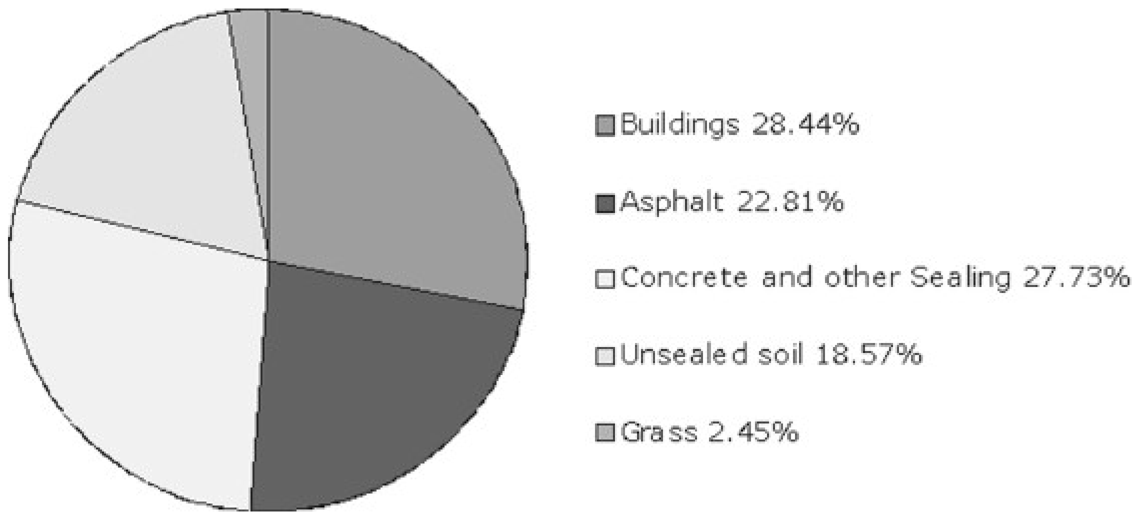

Fig. 2: Model statistics pie graph: Ground use and leaf area ratio of the area under investigation (Compiled by the author)

Subsequently (aside from the simulation of the actual situation) nine different scenarios were simulated in order to investigate improvements or degradations on the thermal comfort at pedestrian height. These scenarios concerned as well simple implementations as the synergetic effects of more complex scenarios. Among the numerous possible scenarios, reasonable ones were chosen during the research process. The following scenarios were simulated:

Actual Situation:

- Actual Situation with application of High-Albedo Roofs
- Actual Situation with application of High-Albedo Walls
- Actual Situation with application of High-Albedo Streets
- Actual Situation with application of High-Albedo Street Canyon & Roofs
- Actual Situation with complete Loss of Vegetation
- Actual Situation with application of Green Roofs
- Actual Situation with application of 50% More Trees
- Actual Situation with application of Green Roofs & 50% More Trees
- **Original Situation before urbanization** (circa year 1800)

Results

The simulations visualize that one of the few possibilities to improve thermal comfort in the outside spaces of tropical cities, is represented by the diverse positive effects of plants. The scenario No. 9 proved to be climatically the best and close to the original situation. In contrast highly reflective (high albedo) surfaces (such as mirror glass or white surfaces) tend to elevate mean radiant temperatures in street canyons, lead to glare and thus to the decline of the well-being of humans in the outside space.

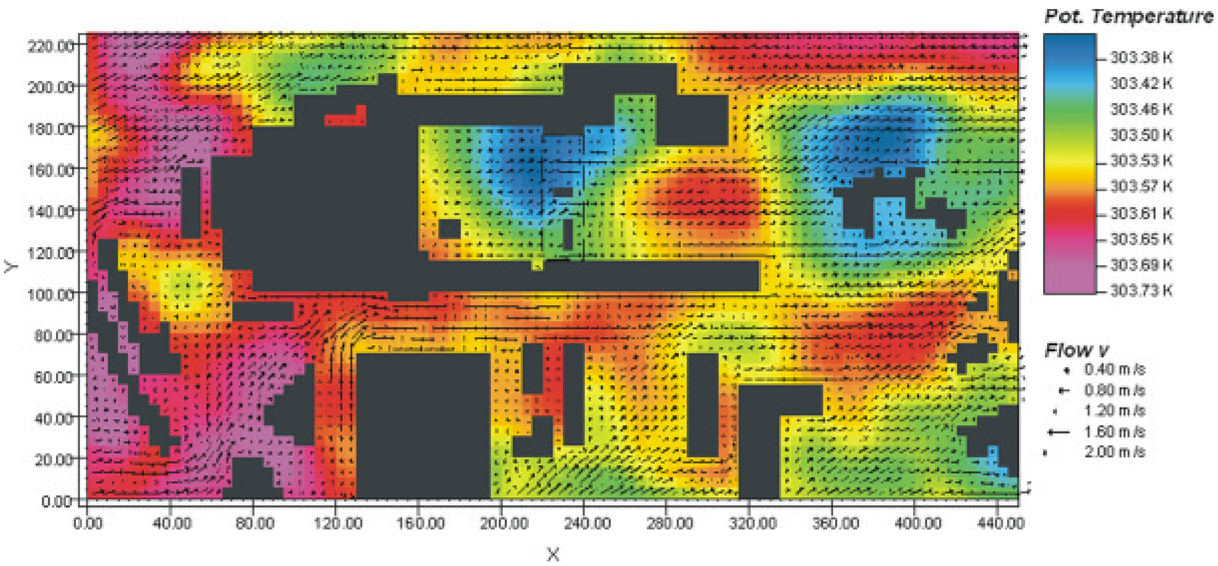

Fig. 3: Thermal Field of the Area under Investigation (ENVImet Simulation)

Distribution of Temperature on the 06.03.92 (Average Summer Day) at 21:00
During the work process with ENVImet, also some imperfections of the program i.e. various problems in calculating the flow have occurred. It was also shown that the cooling of the simulated atmosphere is much stronger delayed than the real values measured at a height of 1.50 meters indicate for the real atmosphere. (But this may also be due to the wind, which affected measurements in situ in the late afternoon). It was also found that the ranges of ? T and ? H (local differences/ distribution of temperatures and humidity) in the model domain could not be modeled in the stronger differentiated way they occur in reality in tropical environment. The air temperatures i.e. of the computed domain range usually between 0.3K and 0.6K, while values measured during the field monitoring range between 1K and 3K. As a reference Miranda et al. (1993) i.e. have measured maximum differences in temperature outside and inside the layers of cacao plantation in tropical hot humid climate around 2 ± 0.5K. It is most probable that the extremes of the results are diluted because of simplifications, parameterizations of the program. It is highly desirable that future versions of ENVImet continue to improve and that it will be possible to erase these and other slight problems in order to widely apply this highly innovative tool for the future planning (and urban redevelopment) of more climate conscious sustainable tropical cities. In addition research and the collection of local data are required to advance the adaption and valorization of ENVImet for tropical means.

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