Evaluation of the effect of densification of the built environment on outdoor thermal comfort in warm-humid Dar es Salaam, Tanzania

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2015

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dated : 1 July 2015

Abstract

Many cities in the tropics suffer from increasingly higher temperatures due to both global and urban warming. Often the thermal conditions are worsened by poor urban design including lack of shade and poor ventilation. Moreover urban regulations are often poorly adapted to the climate and there is often a lack of vegetation. In Dar es Salaam, Tanzania – which has one of the highest urbanization rates in the world mainly occurring as horizontal growth – the thermal conditions are poor, especially in the afternoon during the period October to April (Ndetto and Matzarakis, 2013). In response to this, the urban planning authorities act to densify the city, especially the central areas. This is done through redevelopment schemes which allow considerably higher buildings than previous regulations. The main aim of this paper is to evaluate the effect of the proposed densification of the built environment on microclimate – especially wind speed, solar exposure and shade. The aim is also to suggest how the proposed redevelopment schemes could be modified in order to enhance the microclimate. The study is mainly based on numerical simulations of the influence of parameters such as building form and vegetation using the model ENVI-met. This study provides some preliminary recommendations to urban planners and designers in Dar es Salaam on how to design thermally comfortable, high-density urban areas as regards street orientation and distances between buildings.

Keywords: Climate-conscious design, Computer simulations, Dar es Salaam, Urban design

1. Introduction

Many cities in the tropics suffer from increasingly higher temperatures due to both global and urban warming. Often the thermal conditions are worsened by poor urban design including lack of shade and poor ventilation. Except for the expected increase in air temperature, extreme weather events such as heat waves will be more common in the future leading to increased occurrence of heat stress and heat-related diseases as well as diminished performance of both mental and physical tasks. Cities are especially sensitive since, in addition to global warming, they are also exposed to the urban heat island effect. Increased temperatures will also lead to increased energy use for air-conditioning and consequently increased emissions of greenhouse gases.

Africa is currently experiencing a very fast rate of urbanization. Today's 40% urban population is predicted to increase to 61.8% by 2050 (UN-Habitat 2009). Dar es Salaam, Tanzania, has one of the highest urbanization rates in the world mainly occurring as horizontal growth. As a response to this, the urban planning authorities act to densify the city, especially the central areas.

With few exceptions, urban planning regulations in most countries of the world have their origin in the Western town planning ideas that emerged during the beginning of the 20th century. Although adjustments have taken place over the years the principles have to a large extent remained the same. Urban modernism has among other things contributed to low plot coverage, large setbacks, wide roads for large vehicular movement, separation of land use functions and low densities, especially for high income people. Moreover, these regulations are often poorly adapted to the local culture and climate (e.g., Yahia and Johansson 2013).

This study is part of an on-going research cooperation between Lund University and the University of Gothenburg, Sweden. The main aim of this paper is to evaluate the effect of the proposed densification of the built environment on the microclimate – especially wind speed, solar exposure and shade. The aim is also to suggest how the proposed redevelopment schemes could be modified in order to improve the microclimate.

2. Study area

2.1 Historical development

Dar es Salaam, located on the eastern coast of the country along the Indian Ocean, is the largest city of Tanzania. The city, which is situated on a relatively flat coastal plain, has a population of over four millions in the metropolitan area. Due to rapid urbanization the city nearly doubled its population in the last two decades (Ndetto and Matzarakis, 2015). The annual growth of 4.4% is one of the highest in the world (Ndetto and Matzarakis, 2013) and as a consequence an estimated 70% of the city's population are expected to live in informal (unplanned) neighbourhoods (Rasmussen, 2013).

Founded by Arabs in the middle of the 19th century, Dar es Salaam was colonized by Germans in the end of that century. After the 1st World War the British took over and administrated the city until 1961. Soon after independence from the British the population started to grow more rapidly. Dar es Salaam is characterized by a radial structure with settlements along four major roads which all originate from the city centre. Informal settlements of middle and low-income families have emerged in between the main roads in a pattern of compact, low-density residential areas, contributing to urban sprawl and inefficient use of land (Rasmussen, 2013; Lupala, 2002). High-income housing is found in the coastal areas north of the city centre where low-rise and low-density development dominates with higher vegetation cover.

2.2. Urban renewal and redevelopment

Urban renewal schemes in Dar es Salaam have been launched lately due to deterioration of housing and infrastructure services as well as increasing land values. The privatization of Tanzania's housing and real estate markets has led to rapid transformations and reconstruction activities in the central areas of the city. These development trends have generally been uncoordinated and characterized by gradual redevelopment, lack of adequate urban planning standards to guide vertical development and inadequate integration of landscape aspects in the design. The redevelopment schemes are meant as guidelines to provide a framework for implementation of renewal plans to assist urban planners and managers in preparing, controlling and coordinating urban renewal processes in the inner city areas in Tanzania. (MLHHSD, 2007)

So far redevelopment schemes have been developed for the City Centre, the densely populated commercial and residential area Kariakoo, the mainly residential area Upanga and the high-end and low-rise residential area Oyster Bay. This paper concentrates on the neighbourhoods Kariakoo and Upanga, which have distinctly different characteristics as regards urban morphology and building types.

The neighbourhood Kariakoo has an orthogonal street pattern with a large central marketplace. It was conceived already during the German colonial period, and was mainly aimed for the local African population. Buildings were originally one or two-storey so-called Swahili houses, following local traditional patterns. In the middle of the 20th century medium-rise buildings of 3 to 4 storeys with flat roofs started to be built and replaced partly the Swahili houses. High-rise buildings have been introduced in recent years. The land use is mixed including commercial, residential and institutional buildings. Kariakoo, which is practically devoid of vegetation, is known for its dynamic market and its multitude of small shops along the streets. (MLHHSD, 2002; Lupala, 2002). The redevelopment scheme from 2002 suggests a considerable increase in population density through increased building heights while mainly maintaining the original street pattern. The proposed building heights for different zones are shown in Fig. 1.

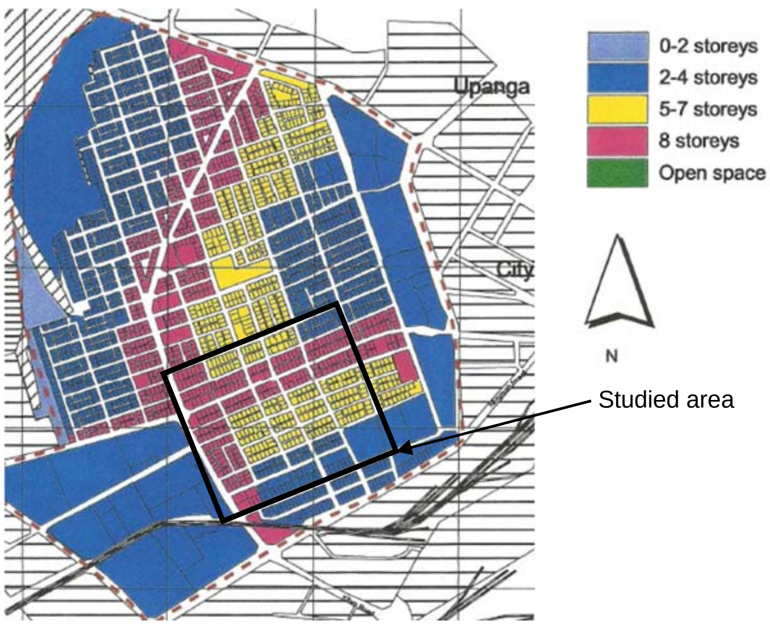


Fig. 1 Proposed building heights for Kariakoo according to the redevelopment scheme (MLHHSD, 2002). The studied area is shown in the black square.

The neighbourhood of Upanga was originally planned in the 1930s as a European garden-city type for residential use and with winding long streets and villas surrounded by greenery. Since the 1970's it has been a prominent residential area for government officials and a centre for government functions and public services (Lupala, 2002). The neighbourhood is today primarily a residential and institutional area with a medium density, typically two to three storey buildings, including both apartment buildings and individual houses; recently areas of high-rise buildings have started to be built. The area is characterized by tree-lined streets and trees are also very commonly found in front- and backyards. The redevelopment scheme from 2011 suggests a considerable increase in population density through radically increased building heights while mainly maintaining the original street pattern (MLHHSD, 2011). The proposed building heights for different zones are shown in Fig. 2.

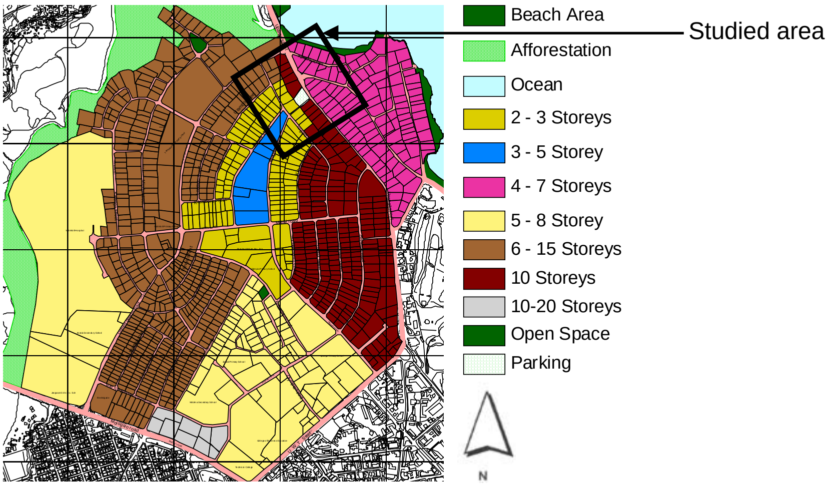


Fig. 2 Proposed building heights for Upanga according to the redevelopment scheme (MLHHSD, 2011). The studied area is shown in the black square.

2.3 Climate conditions

Dar es Salaam is characterized by a warm humid climate which is especially uncomfortable in the afternoon and especially in during the period October to April (Ndetto and Matzarakis, 2013, 2015). During this period afternoon temperatures reach 31°C, the vapour pressure is around 30 hPa, solar radiation is intense and wind speeds are low. There are two rainy seasons; a shorter period between November and December as well as a longer and more intense period between March and May. According to Ndetto and Matzarakis (2013) the Physiologically Equivalent Temperature (PET) reaches values between 35 and 40°C in afternoons in February. The prevailing wind direction during the hottest months (February-March) is from Northeast. The dominating wind direction for most months (May-October) is however from south-southwest. The wind roses based on measurements at the roof of a 12 m high building in the city centre of Dar es Salaam is shown in Fig. 3.

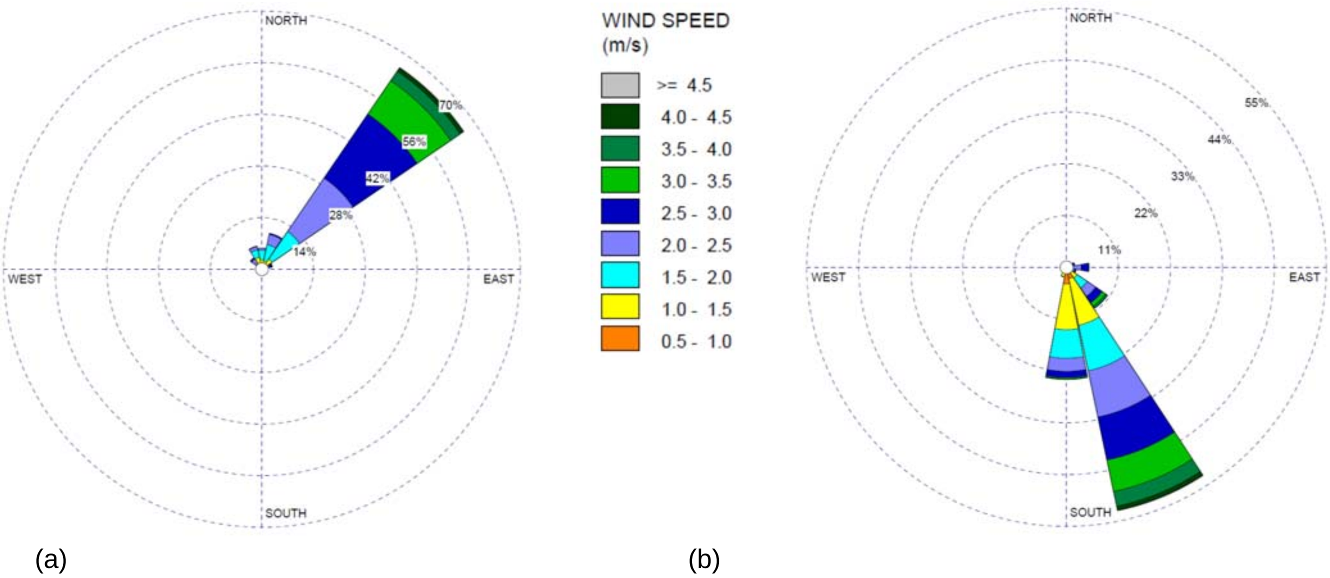


Fig. 3 Calculated Wind roses for Dar es Salaam based on measurements. (a) February 2015, (b) July 2014.

3. Methodology

A climate station measuring air temperature, relative humidity, direct and diffuse solar radiation as well as wind speed and direction was mounted on the House of Culture in the city centre in May 2014. Sampling frequency is 10 minutes.

Microclimate simulations were carried out using ENVI-met 3.1 (Bruse, 2013). The program uses a three-dimensional computational fluid dynamics and energy balance model. The hottest and most uncomfortable period in Dar el Salam is February–March and consequently simulations were made for 28 February. In February the main wind direction is from northeast. A complementary simulation to cover the dominating wind direction from south-southwest was also carried out. For all investigations, the simulated period lasted from 5:00 Local Time (LT) in the morning until 18:00 in the afternoon in order to include the maximum air temperature, which normally occurs at 14:00. The two simulated areas have about the same model size, the Kariakoo model is 570 m x 540 m (grid resolution dx and dy = 4 m) and the Upanga model is 420 m x 420 m (dx, dy = 3 m). The vertical grid resolution dz was set to 3 m for both models. In Kariakoo it was assumed that the current dense footprint area was maintained despite the increase in building height. In Upanga on the other hand, the current plot coverage was increased only somewhat in order to maintain the high amount of greenery which characterizes the neighbourhood. The simulated areas are shown in Fig. 4. See also Figs. 1 and 2. The studied areas were chosen so as represent several zones with different building heights within each neighbourhood.

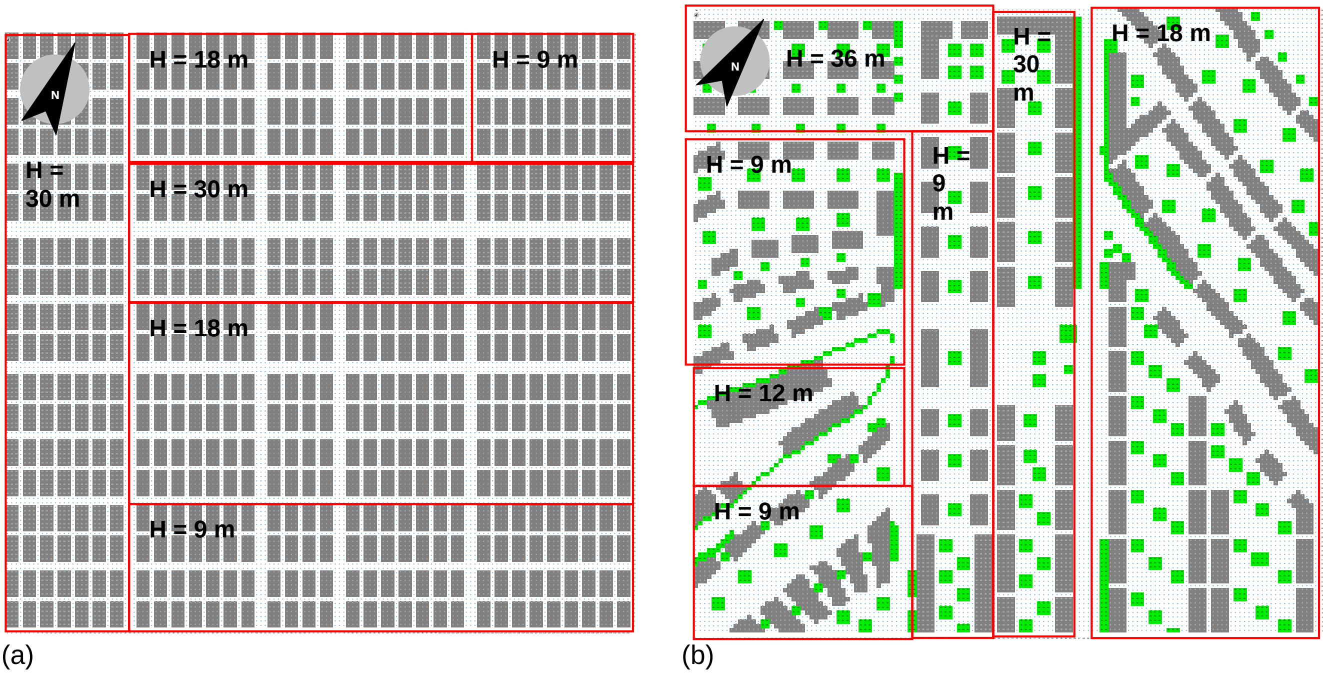


Fig. 4 Physical characteristics (area input files) of the simulated areas, where (a) Kariakoo, (b) Upanga.

4. Results

Preliminary results are shown in Figs. 5-7. Fig. 5 shows the mean radiant temperature for the two neighbourhoods Kariakoo and Upanga at 12.00 hours. In the case of Kariakoo, there is a fairly high amount of shade in general. Especially the high-rise buildings (H = 30 m) give good shade at street level whereas the medium-rise buildings (H = 9 m) are less efficient. In Upanga the shade pattern is worse than for Kariakoo in spite of a much higher amount of vegetation. Within Upanga the areas with more high-rise buildings (H = 30 and 36 m) give by far the best shade. Before and after solar noon there will evidently be more shade in both areas due to lower solar angles.

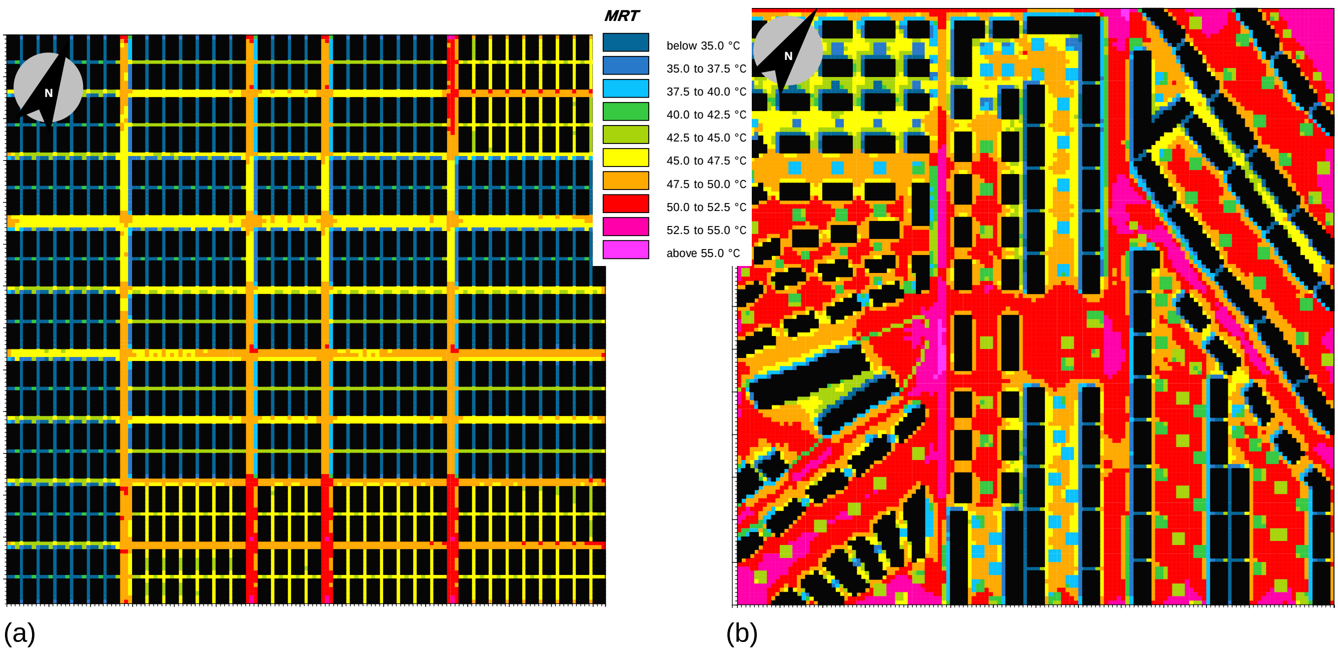
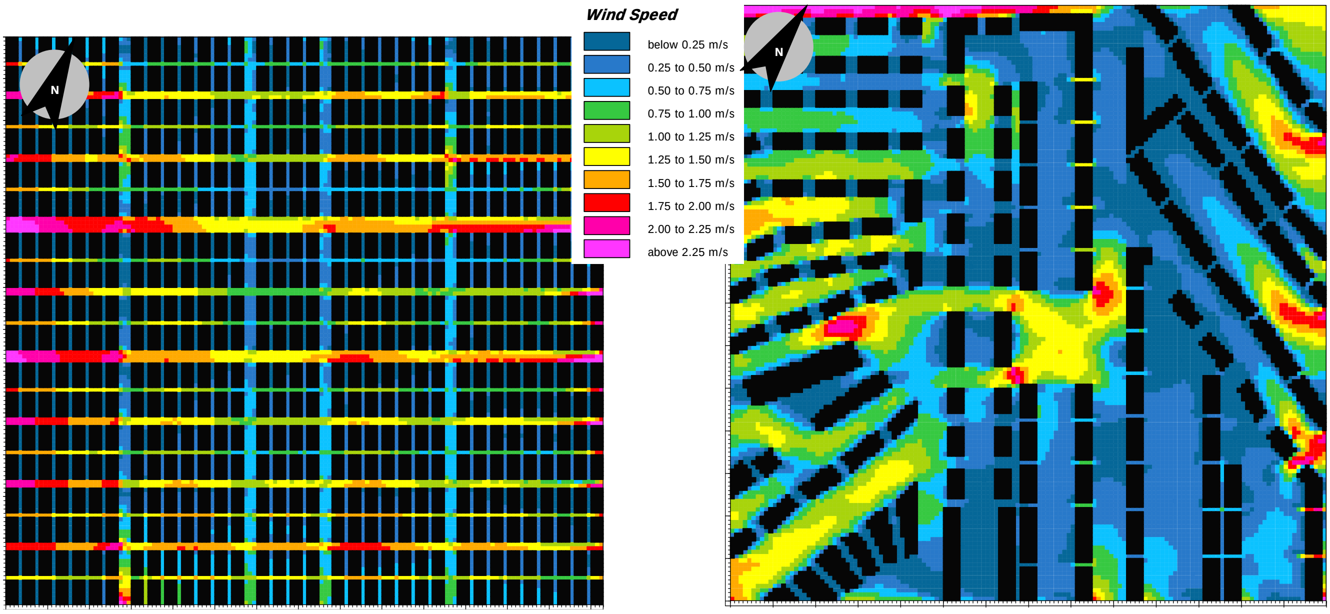


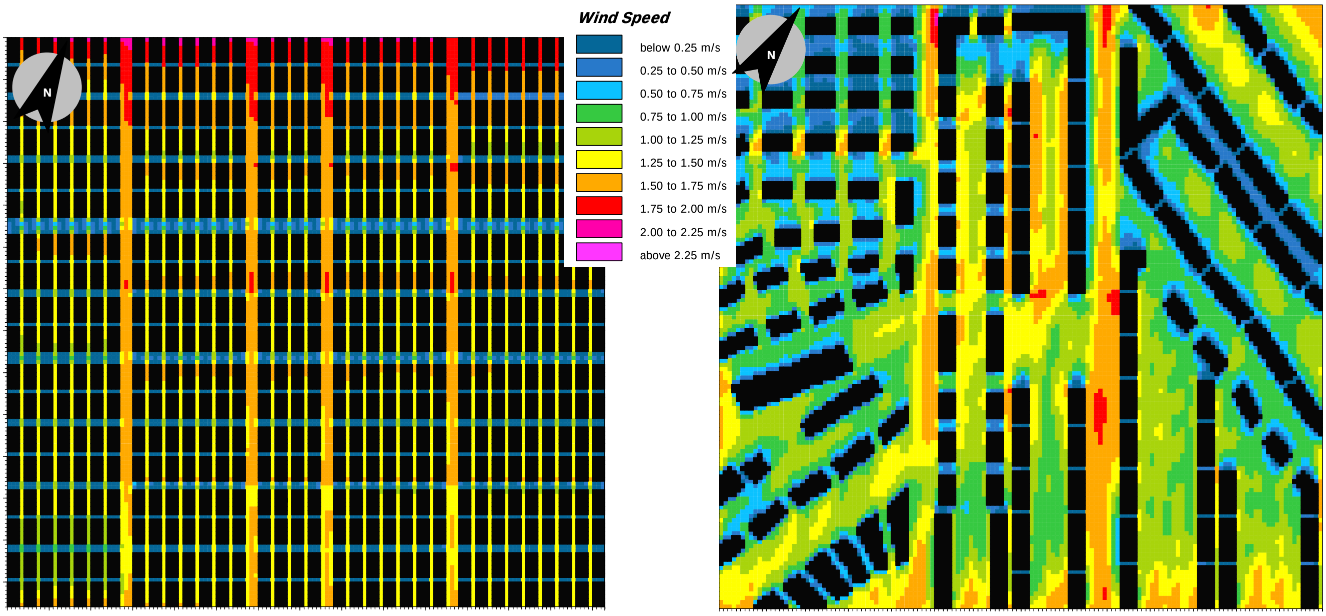
Fig. 5 Mean radiant temperature at 1.2 m at 12:00 on 28 February in (a) Kariakoo, (b) Upanga.

Figs. 6 and 7 show the wind speed pattern for Kariakoo and Upanga. In Kariakoo wind speeds are low in general but the streets that are almost parallel to the wind direction have a bit higher wind speeds, especially the wider streets. The wind speed around the buildings is generally very low and ventilation of the buildings is likely to be poor. In Upanga wind speeds are also low, especially in areas with short distances between buildings (e.g. the area to the right in Fig. 6a where the required setbacks are very small). In the zones where larger setbacks are required, such as to the left in Fig. 6b, wind conditions are better. It is noted that the closely spaced buildings to the right in Fig. 6b act as a barrier for winds coming from northeast.



(a) (b)

Fig. 6 Wind speed at 1.8 m on 28 February, wind coming from northeast, in (a) Kariakoo, (b) Upanga.



(a) (b)

Fig. 7 Wind speed at 1.8 m on 15 July, wind coming from south-southeast, in (a) Kariakoo, (b) Upanga.

The pattern for the other prevailing wind direction, south-southeast, is similar. However, in Kariakoo it is the streets oriented NW-SE that are now well ventilated. In Upanga the developments next to the Indian Ocean act less as a wind barrier and the area is now better ventilated in general.

5. Discussion and conclusions

The increased building heights as proposed by the redevelopment schemes for Kariakoo and Upanga have a positive effect regarding shade. However as concerns the wind, the increased density leads to decreased wind speeds. Especially in Kariakoo, where buildings are extremely closely spaced, this is likely to lead to poor ventilation of the buildings, see Fig. 8. Some zones of Upanga have also very small setbacks which create a similar problem.

Fig. 8. Example showing newly built high-rise buildings in Kariakoo where the required side setbacks are not respected leading to poor ventilation inside the buildings.

Considering the prevailing wind directions the octagonal street pattern in Kariakoo is good since the streets are oriented according to the prevailing wind directions. In Upanga the street pattern is more irregular but several streets have proper orientation there as well. In Upanga, however, the buildings in the north-east of the area tend to block the north-easterly winds during the warmest part of the year (February – March).

The results indicate that rather than proposing a uniform increase in building height it would be better to have a variation in building height which would stimulate downwash of wind to pedestrian level. Closely spaced high-rise towers should be avoided. This agrees with other studies in the warm humid climate such as Ng (2009).

In future studies the redevelopment schemes of the city centre and Oyster Bay will also be evaluated. Moreover a more profound analysis including the effect of H/W ratio, material properties and type of vegetation will be included. The effect of changing street orientation and widening of streets will be studied as well. In addition thermal comfort indices such as PET and/or UTCI will be calculated.

Acknowledgments

The authors are grateful for the financial support from the Swedish Research Council (VR). We would like to thank Mr Pius Tesha, Mr Charles Mafuro and Mr Ramadhan Humbi at the Ministry of Lands, Housing and Human Settlements Development for providing the redevelopment schemes.

References

Bruse M., 2013: ENVI-met simulation programme. Retrieved from http://www.envi-met.com

Lupala J.M., 2002: Urban Types in Rapidly Urbanising Cities: A Typological Approach in the Analysis of Urban Types in Dar es Salaam. PhD Thesis, Royal Institute of Technology, Stockholm, Sweden.

MLHHSD, 2000: Dar es Salaam Central Area Redevelopment Scheme. Ministry of Lands, Housing and Human Settlements Development (MLHHSD), Dar es Salaam

MLHHSD, 2002: Kariakoo Area Redevelopment Scheme. Ministry of Lands, Housing and Human Settlements Development (MLHHSD), Dar es Salaam

MLHHSD, 2007: Guidelines for the preparation of general planning schemes and detailed schemes for new areas, urban renewal and regularization. Ministry of Lands, Housing and Human Settlements Development (MLHHSD), Dar es Salaam., 31 p.

MLHHSD, 2011: UpangaArea Redevelopment Scheme. Ministry of Lands, Housing and Human Settlements Development (MLHHSD), Dar es Salaam

Ndetto E.L. and Matzarakis A., 2013: Basic analysis of climate and urban bioclimate of Dar es Salaam, Tanzania. *Theor Appl Climatol.,***114**, 213-226

Ndetto E., Matzarakis A., 2015: Urban atmospheric environment and human biometeorological studies in Dar es Salaam, Tanzania. *Air Qual Atmos Health,* **8**, 175–191

Ng E., 2009: Policies and technical guidelines for urban planning of high-density cities – air ventilation assessment (AVA) of Hong Kong. *Building and Environment,* **44**, 1478–1488

Rasmussen M.I., 2013: The Power of the Informal Settlements – The case of Dar es Salaam, Tanzania. *Planum - The Journal of Urbanism*, **1**, p. 26

UN-Habitat, 2009: Planning sustainable cities: Policy directions. Nairobi: UN-Habitat.

Yahia M.W., Johansson E., 2013: Influence of urban planning regulations on the microclimate in a hot dry climate: The example of Damascus, Syria. *Housing and the Built Environment*, **28**, 51–65.