Influence of urban water bodies on microclimate and thermal comfort: Case study of Beira Lake, Colombo

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Abstract

This study explores the possibility of urban water body induced city cooling in the Sri Lankan context, with special reference to the Beira Lake, Colombo.

The research method utilises the computer simulation tool ENVI-met to explore
- *The effectiveness of an urban water body in influencing the microclimate.*
- *A water body in comparison to an urban green space of similar magnitude.*
- *Microclimatic and thermal comfort changes within selected sites of specific orientations, encompassing existing and simulated morphology.*
- *The effect of, and on the wind pattern around the lake in a holistic design scenario.*

The simulated results and analysis were limited to the peak time of the day of 14.00hrs of a single day in March.

Conclusions show that contrary to established thinking the Beira Lake has a negative effect on the thermal comfort, yet will facilitate better wind and evaporative cooling potential in the immediate surroundings.

***Keywords**: Urban Water Bodies, Urban Heat Island, Outdoor Thermal Comfort, Warm Humid Tropics, ENVI-met, Sri Lanka*

Introduction

The urban heat island (UHI) effect develops when cities replace their natural land with impervious surfaces, buildings, and other infrastructure (Jauregui, 1997; Liu & Weng, 2008; McMichael, 2000). The UHI effect already produces elevated temperatures in city centres therefore urban design has a key role to pay in reducing the UHI to create safe and pleasant places in which to live and work. Increased surface porosity and water bodies have a role to play in increasing potential cooling through evaporation. (Hathway & Sharples, 2012)

Water bodies form urban cooling islands (UCI) to mitigate the UHI effects. (Sun & Chen, 2012)

The aim of this study is to develop better understanding of the relationship between urban microclimate and water bodies in general and thermal comfort in particular.

The Beira Lake in Colombo, Sri Lanka is taken as the focus of the research, both for its prominent geographical position in the city and the rapid development happening around it.

The results of this study look to provide insight into climate-conscious urban design that incorporates large water bodies as tempering agents, to ameliorate the negative effects of local warming in a warm humid context.

Background

Starting from the early historic cities to the new urban cities, water has been used for architectural purposes. From the inception of our species, coping with the availability – or unavailability – of water resources has been an essential element of human beings' strategies for survival and well-being. Throughout history human ingenuity was manifested in the means by which water was procured, transported and allocated for various uses. The quality, distribution, seasonality and amount of water have been key determinants of subsistence, health and settlement potentials. (Hassan, 2011)

The classical architectural language applied to the cities has included the waterfront and water crossing, serving to comprise the water element in a cohesive architectural language. The river settlements, which were to become great cities, had originated in harmony with the water edge. (Wylson, 2013)

Relationship of Urban Water Bodies, UHI and Outdoor Thermal Comfort

The urban microclimate is closely correlated with the types and patterns of landscape in the urban environment. One of the main reasons of UHI effect, are changes in the thermal properties of surface materials and lack of evapotranspiration through lack of vegetation and water bodies in urban areas. Water, is matter, which has a high heat bearing capacity and acts as medium of evaporative cooling in hot humid regions. Evaporative cooling is a physical phenomenon by means of which typically into surrounding air, cools an object or a liquid in contact with it. Latent heat, the amount of heat that is needed to dry up the liquid, is drawn from the air. (Szokolay, 2005)

The combination of the moisture content in the air provided by a water body and the blowing potential of the wind may strongly affect the microclimate conditions of an urban area, leading to a milder thermal environment. (Masiero & de Souza, 2013)

Fanger's thermal comfort equation shows that high humidities can be rewarded by the lower air and radiant temperatures. Although it is generally assumed that the primary cause of thermal discomfort is humidity in the tropics, studies have shown that at lower air temperatures of humidity effect on comfort is minimal. It reveals that carefully controlled humidity with shading can create thermal comfort. Thus, the potential of water in cooling is substantial even in the humid regions. However, care must be taken not overload the already heavy relative humidity of the tropics. (Emmanuel, 2005)

Water and Climate Sensitive Urban Design

Johansson et al, 2006, conducted a study in the coastal region of Colombo, Sri Lanka to find potential of sea breeze in cooling the urban outdoor areas, they found “In the weak wind regime of the tropics, another possibility is to induce wind flow by the thermal difference that arises at the edges of the water bodies. Differences in the thermal properties of land and water generate water/land breeze at day/night respectively. These wind-flow patterns could plan measures that promote deep wind penetration in to cities.” (Emmanuel & Johansson, 2006).

Emmanuel in 2005, suggests that, to get the maximum benefit from the water bodies

- Locate water bodies in every neighbourhood at the northern/southern corner of the city
- Connect major traffic roots water diagonally
- At larger scale, rearrange the street network to take advantage of the air movement
- Plant trees around water bodies to increase cooling potential of the air

Coutts et al, 2012 presents the concept of Water Sensitive Urban design (WSUD). WSUD provides a mechanism for retaining water in the urban landscape through storm water harvesting and reuse while also reducing urban temperatures through enhanced evapotranspiration and surface cooling. Research suggests that WSUD features are broadly capable of lowering temperatures and improving human thermal comfort, and when integrated with vegetation (especially trees) have potential to meet climate sensitive urban design objectives. However, the degree of benefit (the intensity of cooling and improvements to human thermal comfort) depends on a multitude of factors including local environmental conditions,

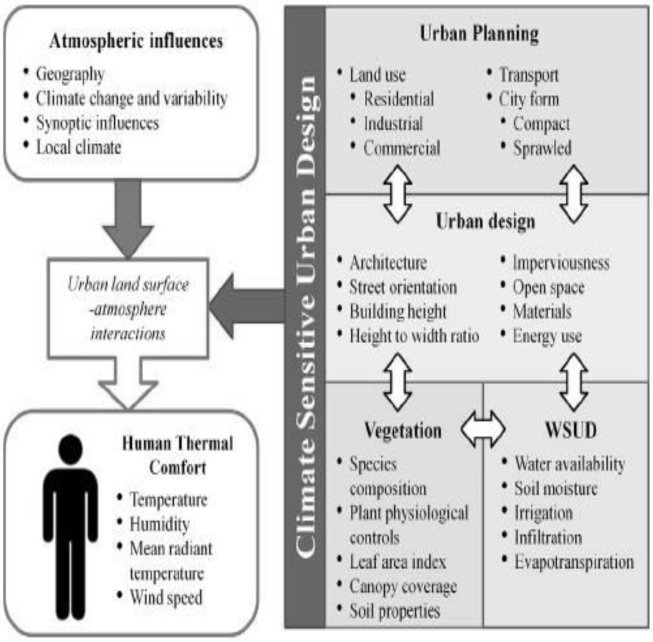


Fig 1- Conceptual diagram demonstrating the conn
ction between Water Sensitive Urban Design and Climate Sensitive Urban Design.
Source - (Coutts et al., 2012)

the design and placement of the systems, and the nature of the surrounding urban landscape. (Coutts, Tapper, Beringer, Loughnan, & Demuzere, 2012)

Ishi et al. (1991), working on a 12.7 ha pond located in the central part of Fukuoka city, recorded a cooling effect of about 3°C up to several blocks downwind and especially during the afternoon hours. In some cities, the rivers crossing urban areas have been recorded as contributors to air purification (Fukuoka, 1997) and microclimate features (Murakawa, 1988; Katayama et al., 1991).

Sun et al., (2012) showed for Beijing, China; the relationship between wetland characteristics and Urban Cooling Island (UCI) intensity can provide useful action points for urban landscape design to mitigate the UHI effects.

- It is necessary to add water areas in big cities and keep them evenly distributed in dense, built-up areas, even though land use development pressures are also very high in those areas.
- The cooling effect of wetlands does not linearly correlate with wetland area. This indicates that the cooling effect has a threshold as the wetland area increases, and it is reasonable to benefit more stakeholders by substituting a large water body with several small water bodies of the same total area.
- The cooling effect of wetlands may be intensified by constructing them in a relatively regular shape because we do not have enough urban land to create wetlands.

(Sun, Chen, Chen, & Lü, 2012)

Evidence of the negative effects water bodies in urban areas was reported by Steeneveld et al., 2014 showed that; Based on weather observations by Dutch hobby meteorologists and a station network in Rotterdam (Netherlands), that water bodies increase rather than decrease the 95 percentile of the daily maximum UHI. The high heat capacity of water suppresses the diurnal and annual cycle over water, and water temperatures remain relatively high after evening and season transitions. This is reflected to the 2 m temperature above and in the surround of the water body, and in a relatively high UHI. (Steeneveld, Koopmans, Heusinkveld, & Theeuwes, 2014)

Similarly, (Perera, Emmanuel, & Mahanama, 2012) comparing the nocturnal cooling capacities (therefore UHI intensity in the urban canopy layer) of specific Local Climate Zones (LCZs) in Colombo, Sri Lanka, showed that the difference between 'LCZ-G-Water' to be warmer, than other LCZs in the land cover typologies. The study showed a 0.62°C UHI intensity. 'Local climate zones' (LCZs) comprises of a new and systematic classification of field sites for heat island studies. The classification divides urban and rural landscapes into 17 standard classes, each defined by structural and land cover properties that influence air temperature at screen height. (Stewart & Oke, 2012)

Method

The aim of the study was to explore the possibility of urban water body induced city cooling in the Sri Lankan context, with special reference to the Beira Lake, Colombo, Sri Lanka.

Within the primary objective the method is focussed on the following areas;

- The effectiveness of an urban water body in influencing the microclimate.
- A water body in comparison to an urban green space of similar magnitude.
- Microclimatic and thermal comfort changes within selected sites of specific orientations, encompassing existing and simulated morphology.
- The effect of, and on the wind pattern around the lake in a holistic design scenario.

The research method is based on the simulation and analysis of the existing and projected urban context. The steps of which are outlined below;

- Case study selection and site selection
- Simplify the existing built fabric as the existing)(base case)
- Computer simulation of the existing selected areas and projected variations using ENVI-met. The projected variations are as follows;
  - Case study 01 - Change urban geometry according to LCZ simplification of urban context. (Existing Case)
  - Case study 02 - Replace the water body with a similar area of vegetation.(Green Case)
  - Case study 03 - Change urban geometry according to maximum UDA proposal development.(High density case)
- Data outputs of the computer simulations –Mean Radiant Temperature (MRT), Wind speed, Relative Humidity.

Site selection - Beira Lake, Colombo

The research focuses upon the Beira Lake and its environs; a distinctive landmark in the city of Colombo. It has reportedly been in existence for nearly five, centuries and once was a larger and deeper body of water, which had a strategic relevance to the ancient fort of Colombo. The lake has been gradually reduced to its present extent of about 65.4 ha from an estimated original extent of 162 Ha mainly due to reclamation carried out for construction of warehouses. It comprises four main basins the East Lake, the Galle Face Lake, the West Lake and the South West Lake. (Nahallage & Piyasiri, 1997)

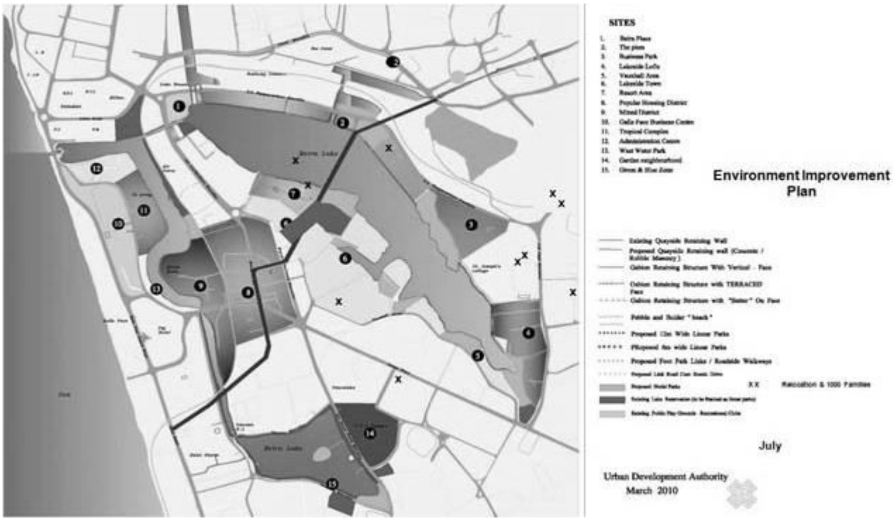


Fig 2- Beira Lake Master Plan - Source - (uda.lk)

The Defence and Urban Development Ministry has launched a massive project spanning over three years to renovate the Beira Lake to enhance the beauty of the city and to redevelop lands adjacent to the lake, for more productive uses. This project includes the construction of linear parks along the Beira Lake. All wastewater outlets including sewerage lines to the Lake are being disconnected. Families living in under developed settlements along the Beira Lake are to be provided housing units with more facilities in the condominium housing schemes under construction. Warehouses and garages by the side of Beira Lake will be relocated for more productive uses. (www.defence.lk last accessed 09.10.2014)

Simplify the existing built fabric and select representative sites

For greater applicability of the findings, a simplification of the urban fabric is adopted. This eliminates the changes due to the 'real world' heterogeneity seen in the urban fabric.

The simplification uses the Local Climate Zone (LCZ) system developed by Iain Stewart (Iain Douglas Stewart, 2011) and application of it for Colombo by (Perera et al., 2012) The LCZ system eliminates the ambiguity of the definition of what is 'urban' and what is 'rural', usually used in UHI reporting. Instead, the comparison is between classified classes. This leads to more efficient decision making for design and policy, where informed judgements can be made on the form of the urban fabric and therefore, its impact on factors like the local climate. Sites were selected around the water body depending on Local Climate Zone (LCZ) and Orientation (in relation to the lake)

Fig 3- Selected Sites

Simulation software - ENVI-met

Computer simulation tool ENVI-met is utilised to simulate the projected variations. ENVI-met is a 3-dimensional non-hydrostatic model for the simulation of surface–plant–air interactions, especially within the urban canopy layer. It is designed for micro scale with a typical horizontal resolution from 5 to 10 m and a typical time frame of 24 to 48 hours with a time step of 10 sec at maximum. The model has been extensively used in recent years in many urban areas, including in warm, humid regions and found to be an effective tool to estimate the local climate, air quality and thermal comfort effects due to urban growth (Bruse 2004).

The model does not express exact physical condition such as contours and is built on a horizontal plane. A shortcoming of ENVI-met is that buildings, which are modelled as blocks, where width and length are multiples of grid cells, have no thermal mass and have constant indoor temperature. Moreover, albedo and thermal transmission (U-value) for walls and roofs are the same for all buildings. ENVI-met was validated for Colombo, Sri Lanka by Emmanuel, & Fernando, 2007.

The simulation scenarios are shown below;

Table 1 - Simulation Matrix

Scenarios	**Urban Geometry**	**Green Cover**
Base case (Existing)	to match existing geometry simplified as LCZs	None
Green case	same as base scenario	10 m (canopy) street trees at 20 m intervals (Stem height = 10m,without water body)
High density case	All buildings in the model area to be as tall as the urban development regulations will permit. (According to proposed zoning plan (2020) city of Colombo).	None

Analysis protocol

The data generated by ENVI-met is visualised using the ENVI-met add-on package LEONARDO 2014. The objective of the analysis is to ascertain the effect of the water body, therefore a system where the overall simulated is visualised becomes important. This is as opposed to point measurements, where other factors in the context, can affect the results. The analysis is limited to 14.00hrs on a particular day. The time is generally assumed to be the warmest time of the day. Iso-contour maps depicting MRT, RH and Wind speed are compared for the differently oriented sites for discussion on the impact of the Beira Lake on the context.

Results and Analysis

Site 'DR' (East) (Fig 4, 5, 6)

In the existing context, the MRT ranges from 27.7 to 65.95 ^{o}C. A replacement of the lake with that of a similar area covered with vegetation is seen push the MRT levels up, with a range 29.5 to 79.9 ^{o}C. Similarly, the high-density (HD) option too pushes the overall MRT range. (Fig 4)

At 14.00hrs, the lake surface is significantly warmer than the vegetated surface. Comparison of the 'existing' and 'green' case scenarios does not show significant variation in MRT values in the built areas around the lake. Although, in the HD case, the MRT change in the outdoors, especially adjacent to the buildings, show marked differences. The shade caused by the taller buildings decrease the MRT intensity. In areas where there are no buildings to shade the environs, the MRT values remain similar.

In terms of Relative Humidity (RH) the MRT differences between a vegetated area and the water body is very significant, with the vegetated area showing markedly lower values. As shown in Fig 5, the RH effects of the lake (existing case) penetrate deep into the urban fabric, resulting in comparatively higher values.

The HD case demonstrates that the taller building fabric blocks the RH flow, therefore beyond the initial buffer of buildings, the RH drops.

The wind shadow created by buildings, especially in the HD case, is clear. Reduction of the wind speed is evident in the green case, where it is understood that trees would hinder wind flow. This is seen on the lake edge, yet in the areas beyond the edge show similar characteristics.

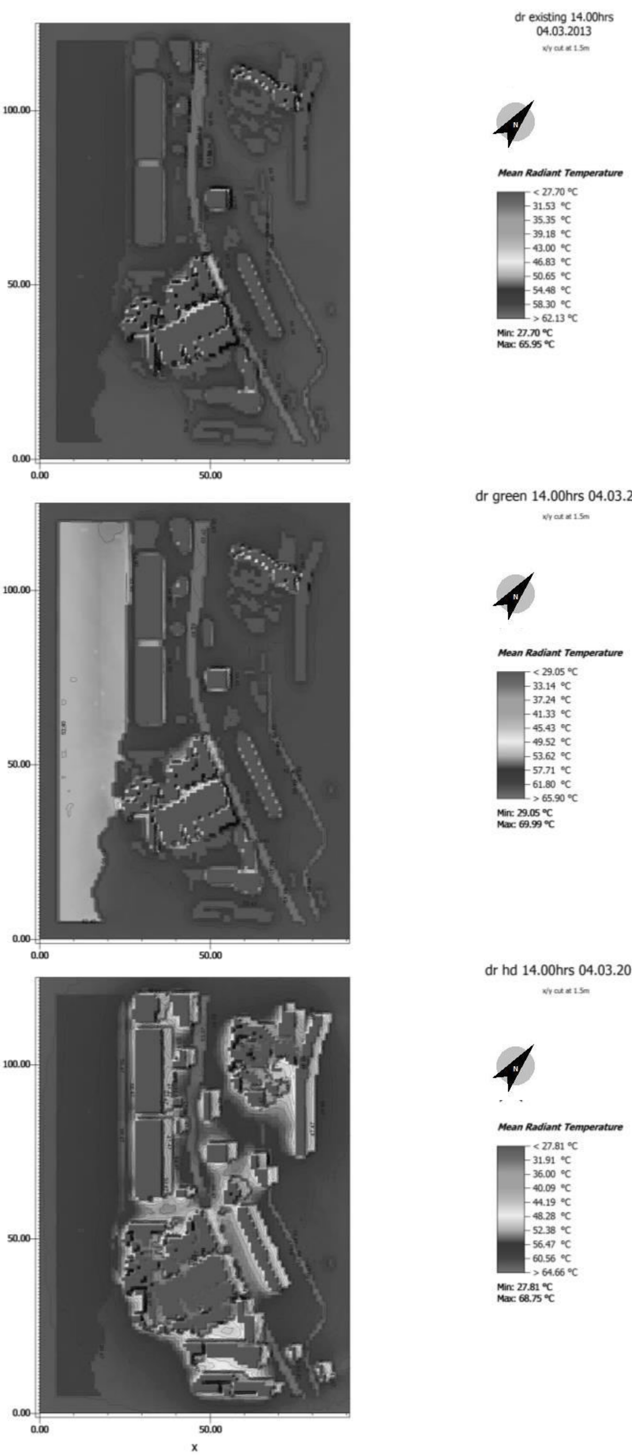


Fig 4 - DR MRT comparison

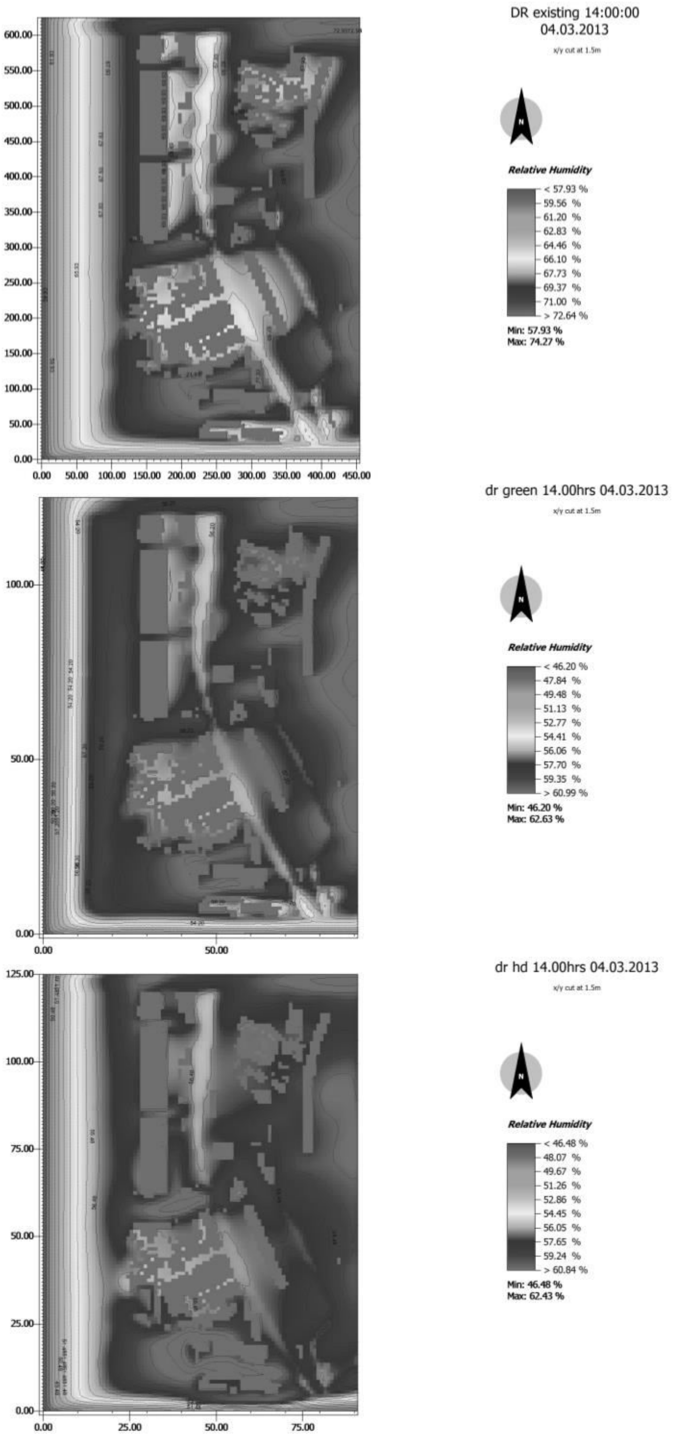
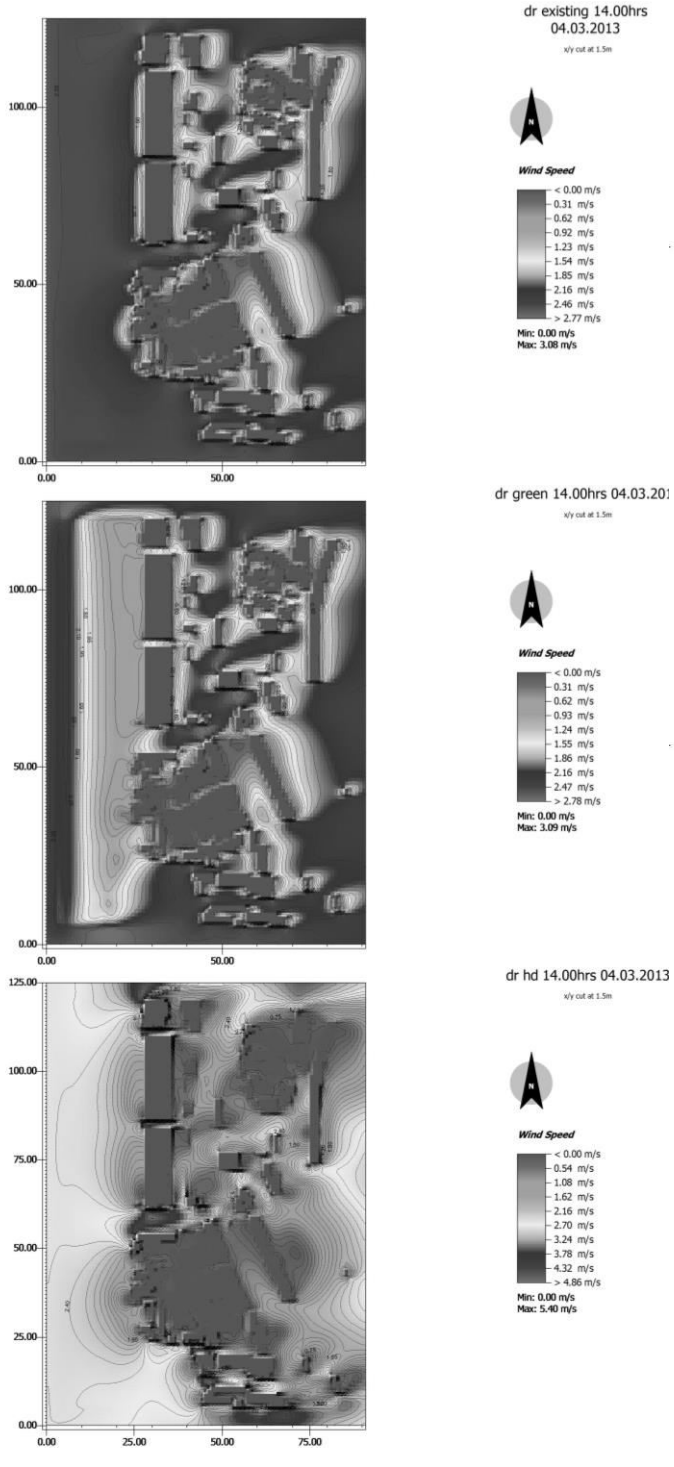


Fig 5 - DR RH comparison



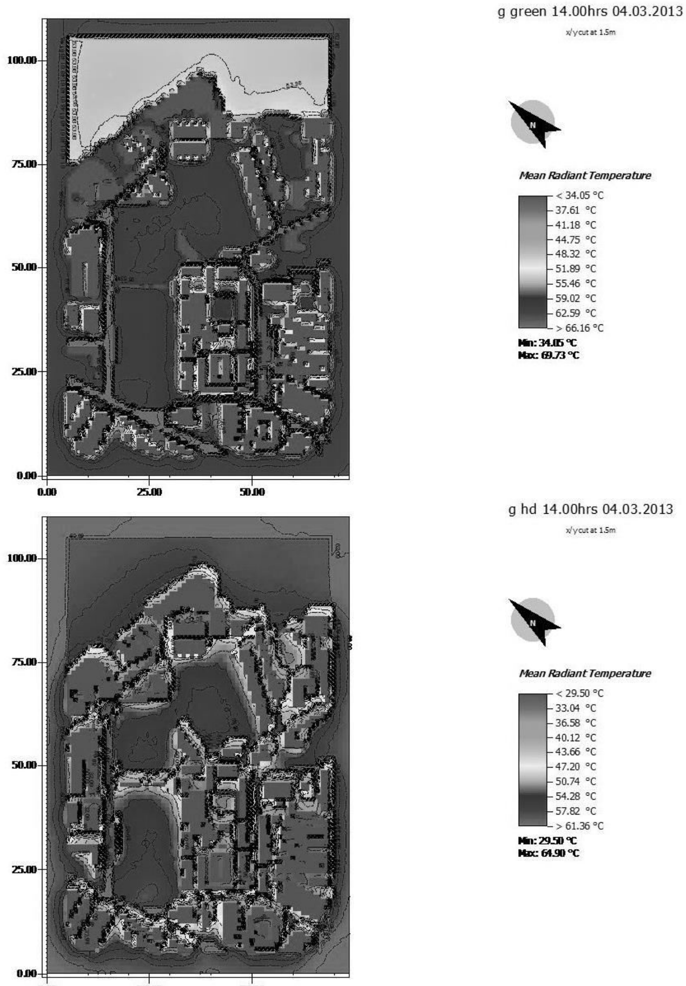


Fig 7 - G MRT comparison

Fig 6 - DR wind speed comparison

Site 'G' (West) (Fig 7, 8, 9)
The analysis compares the 'green' and the 'HD' cases only, caused by data errors for the existing case simulation.

Fig 7 portrays a similar MRT pattern to what is seen for site DR (East), where, the lake area is warmer than a similar green area, HD building fabric creates shadow and therefore cooler. The MRT intensity too, record similar values.

Unlike in the East bank (Site 'DR'), the RH differences seen in the green and HD cases where it showed similar, uniform penetration into the fabric. Here, the RH change for the green case is more rapid. (Fig 8)

The wind speed characteristics are as seen in the preceding site. Fig 9 shows higher values for wind speed at the edges of the Iso-contour plot. This is due to the buffer zones used in the ENVI-met simulation, therefore deemed negligible.

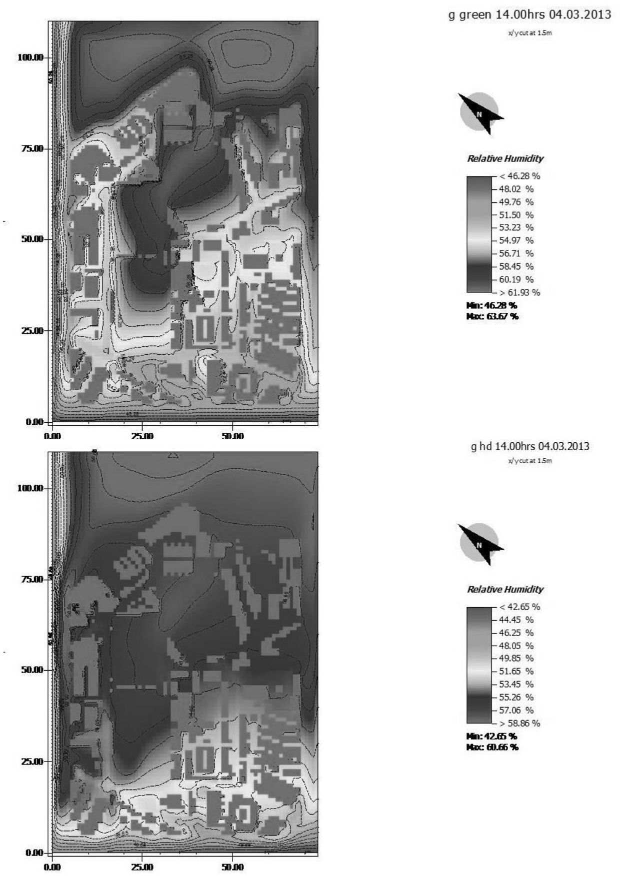


Fig 8 - G RH comparison

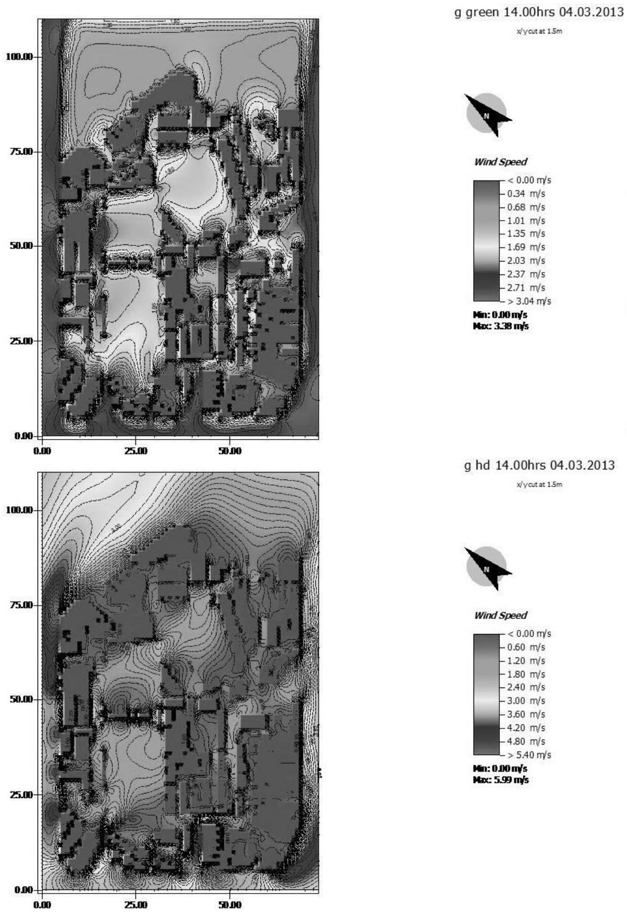


Fig 9 - G WS comparison

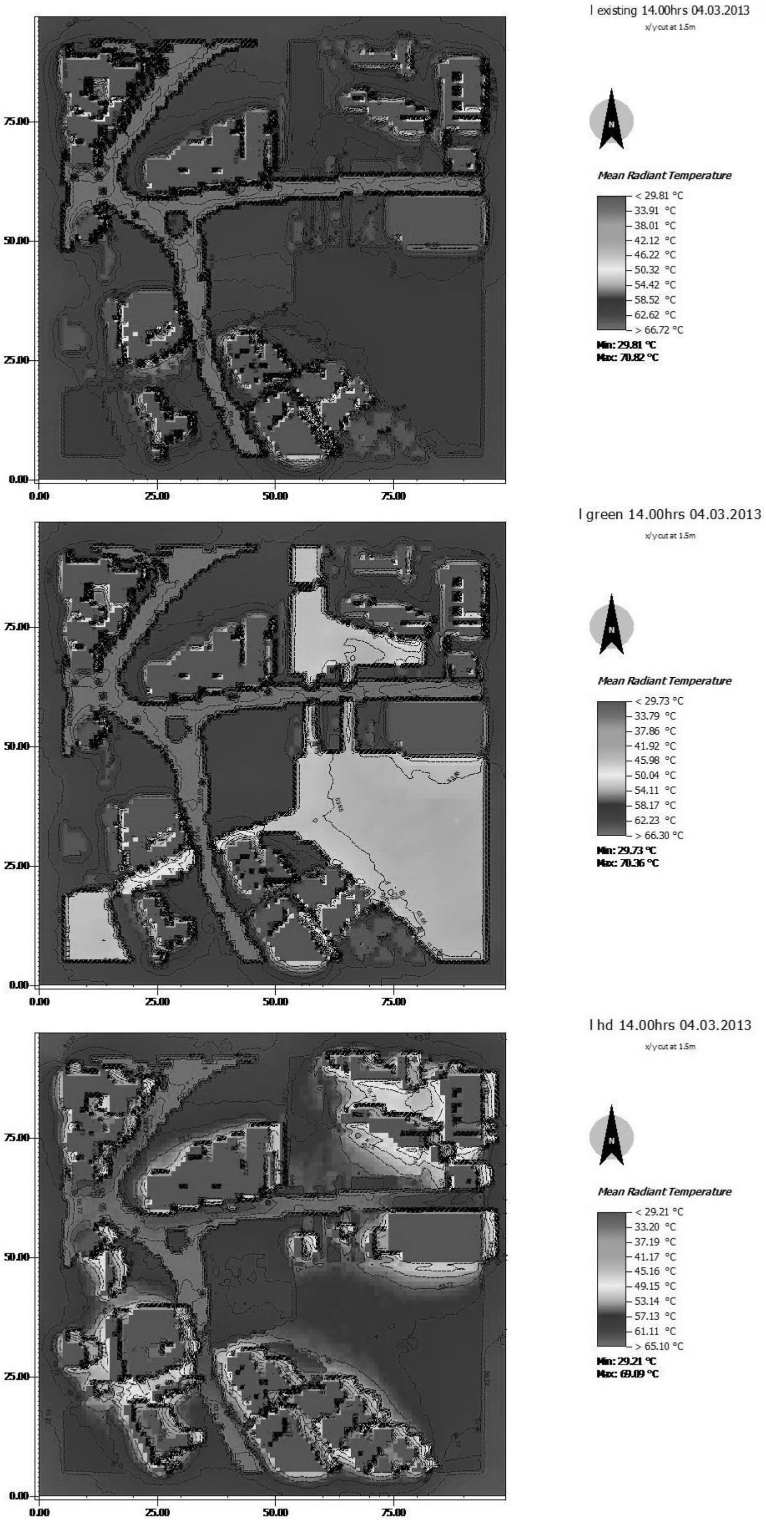


Fig 10 - L MRT comparison

Site 'L' (North) (Fig 10, 11, 12) and Site 'P' (South) (Fig 13, 14, 15)
The sites show similar characteristics seen for the other sites. Thus, the change of geographic location and orientation in relation to the environs of the lake seems to have no effect. Yet, it must be noted that the simulation is limited to single day and time, therefore diurnal and seasonal effects of the sun path and wind are not taken into account.

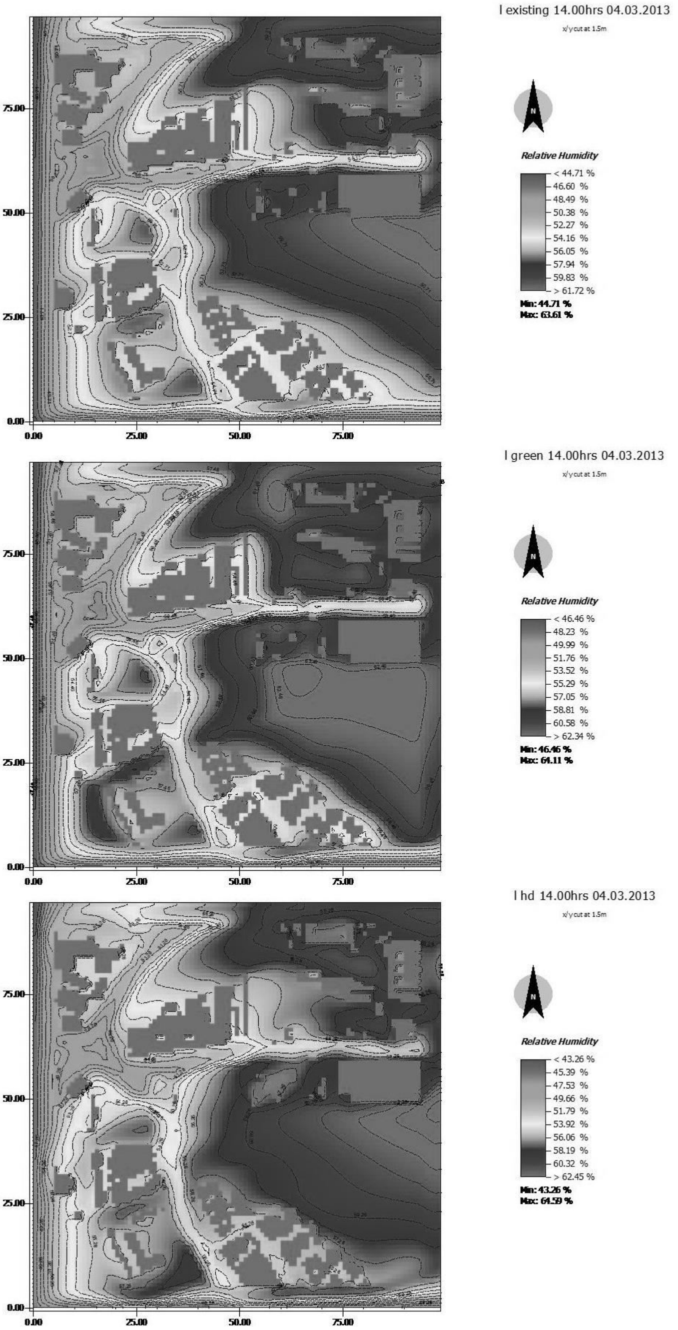


Fig 11 - L RH comparison

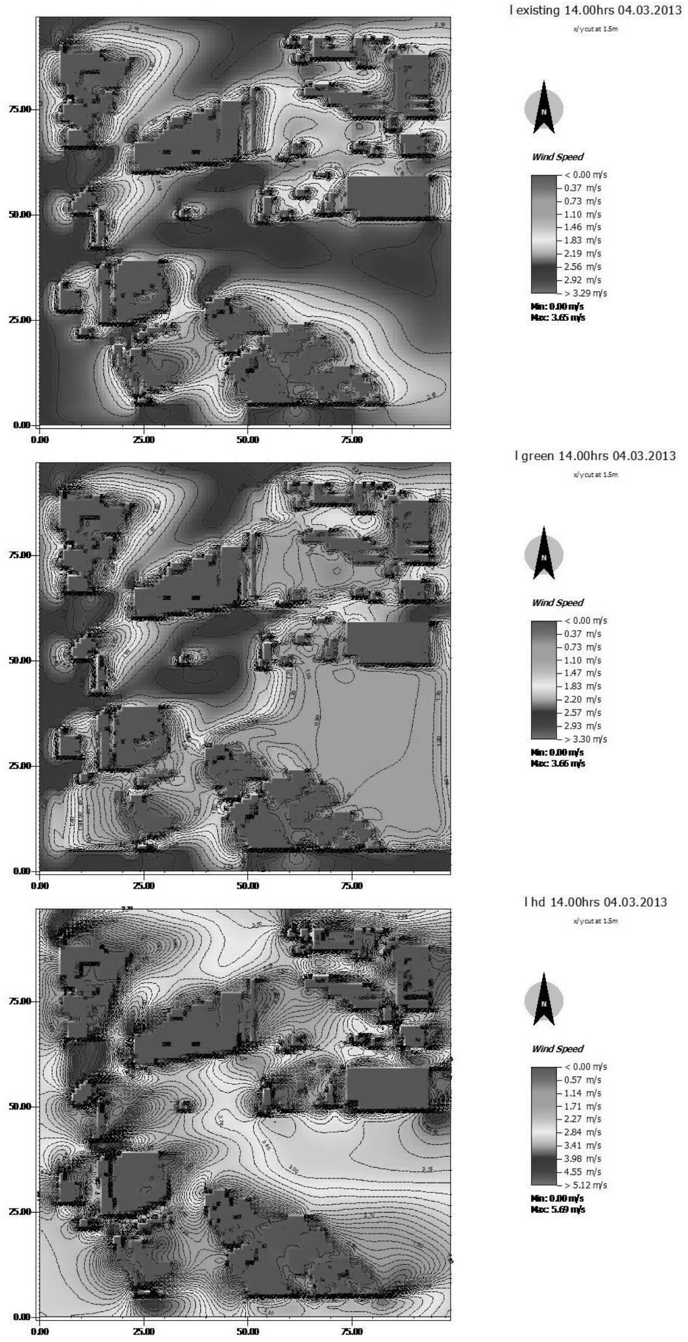


Fig 12 - L Wind Speed comparison

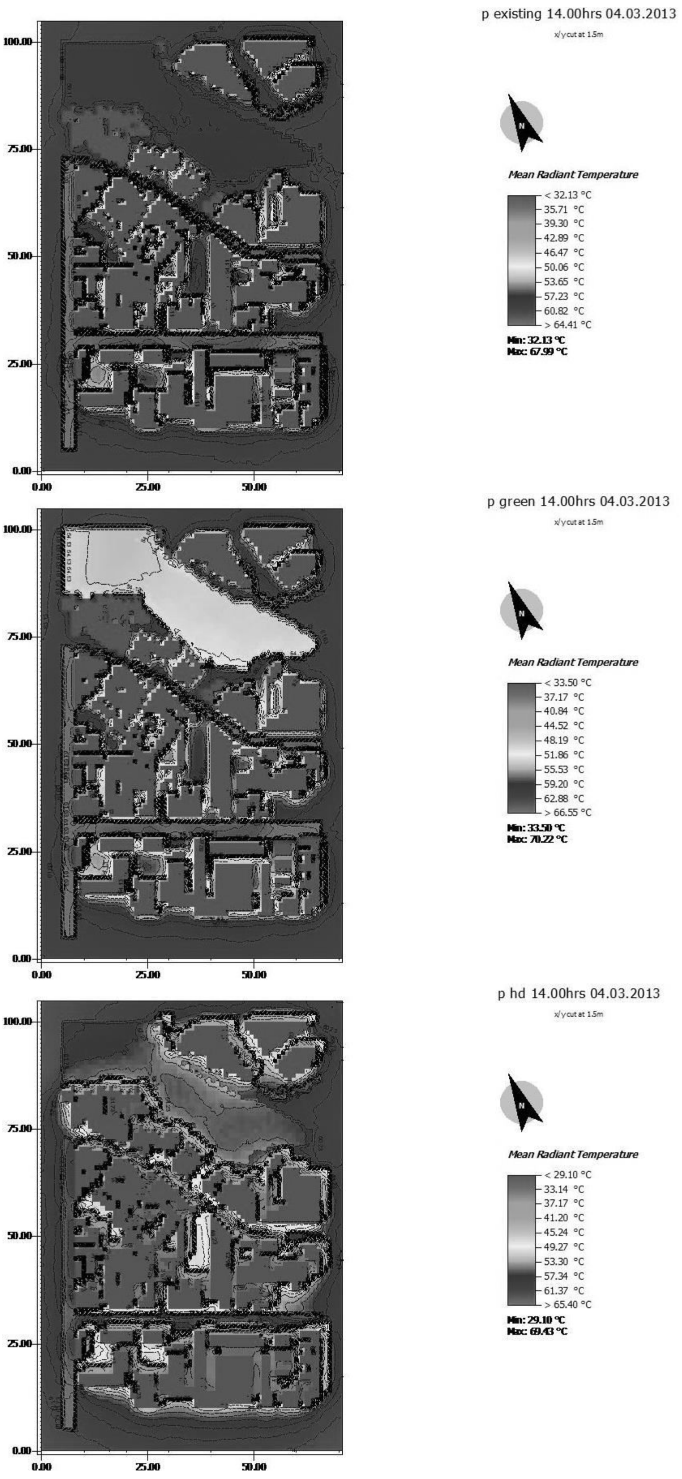


Fig 13 - P MRT comparison

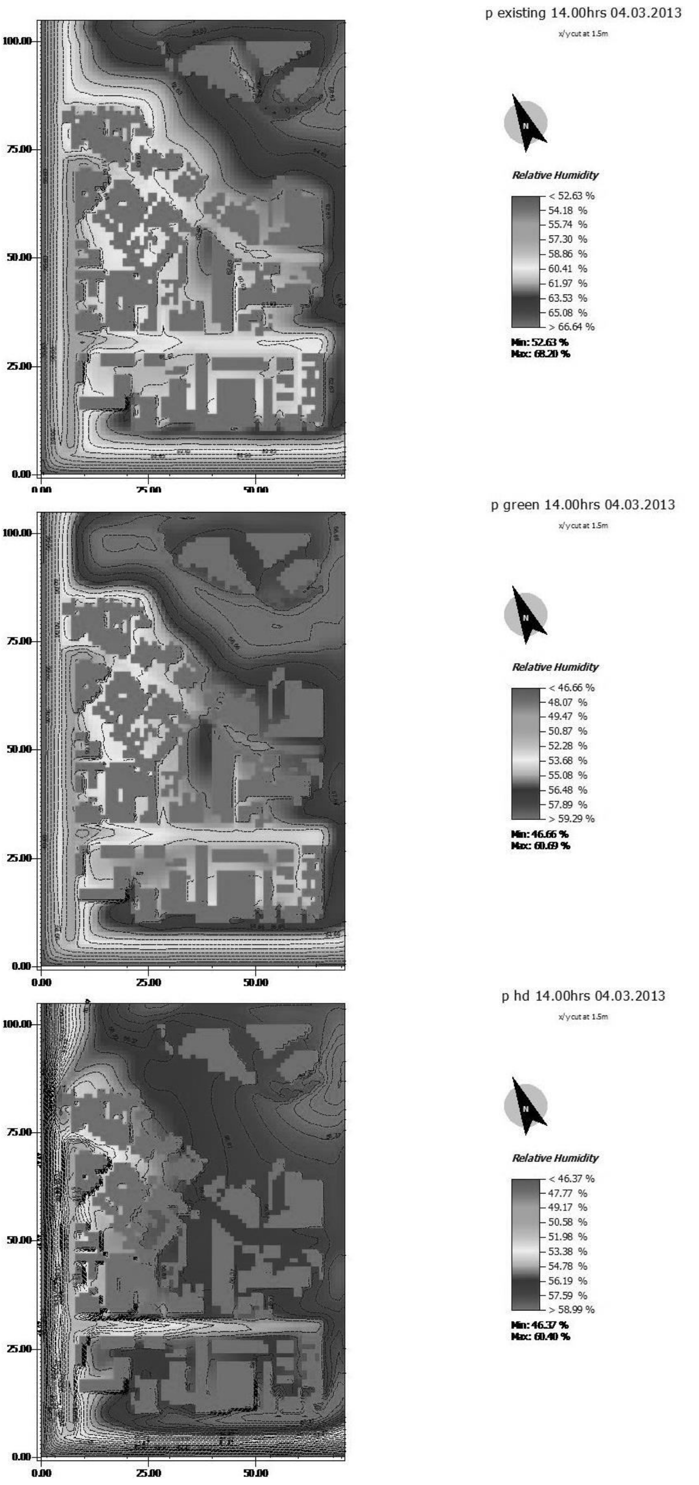


Fig 14 - P RH comparison

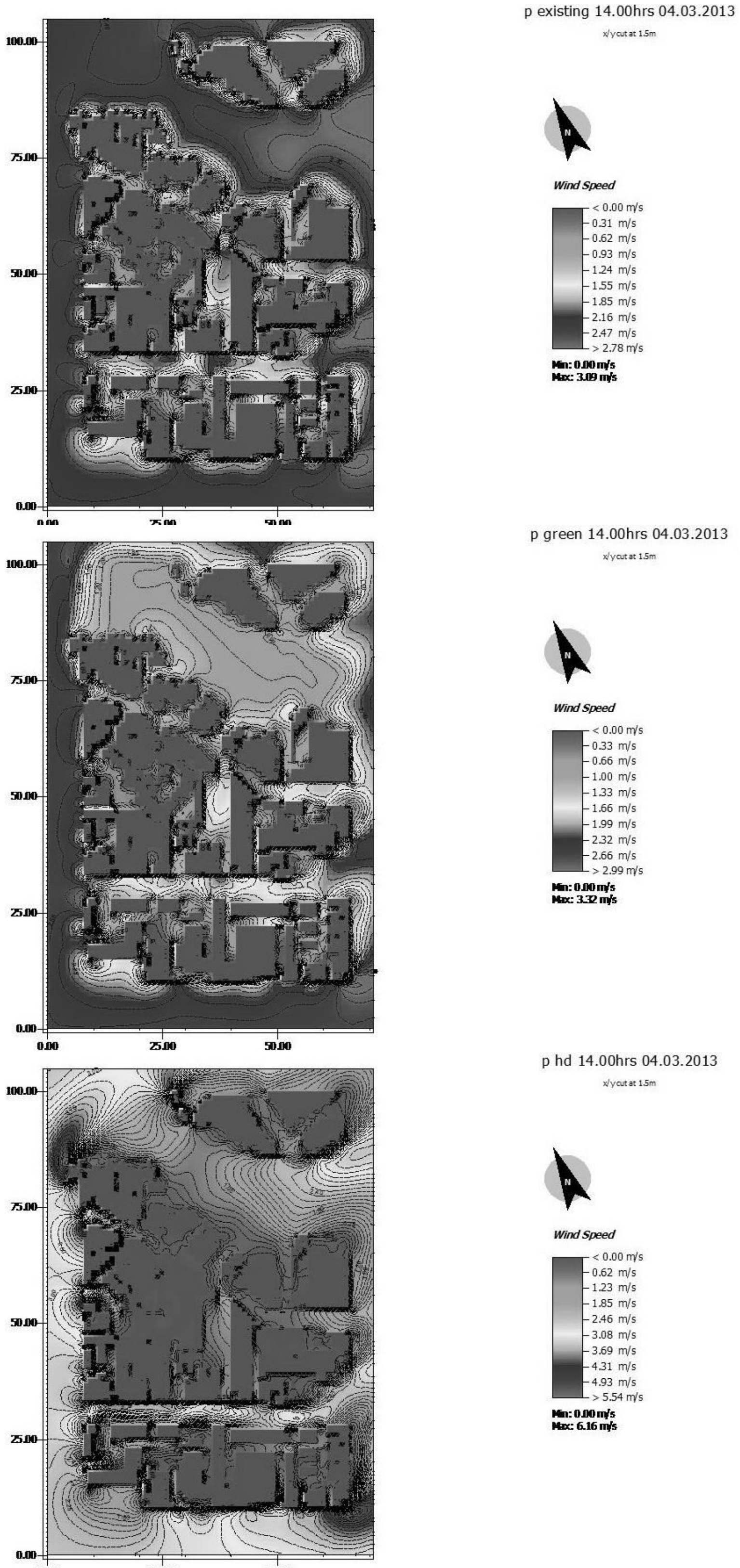


Fig 15 - P Wind Speed comparison

Summary of findings and Implications

The simulations of existing and projected cases show that;

- MRT intensity of the lake surface is warmer than that of the built fabric that surrounds the lake perimeter. Unlike established research discussed above, the Beira Lake in Colombo does not create a 'cool island' at the peak time of the day considered in the analysis. The difference in MRT in the built fabric is more building morphology (and therefore shade) induced rather than by the evaporative cooling potential of the lake. The implications of an urban water body as a UHI mitigation strategy is not applicable for the peak time of day. Although, research shows that it can have a positive effect as an open area that can offer essential wind paths into otherwise heavily built up-areas in a city.

- A similar 'green' area that would hypothetically replace the lake is cooler in terms of MRT. There is minimal difference in MRT intensity between the two cases in relation to the areas between buildings, the impact of the green space is confined to the boundaries of such an intervention.

- A green option adversely affects the wind speed and RH at the edge of the lake. Yet, the simulations show similar values for the two variables, deeper into the built fabric. The effect of a green space is more local than that of a large water body. If the focus is on creating thermal comfort in specific areas, a green space is more advantageous, while the water body option has more far reaching advantages for areas of the fabric extending beyond its confines.

- The HD options create cooler areas in the immediate vicinity of the buildings. Yet, has a negative affect for both wind speed and RH flow. Thus, restricts the use of ventilation and evaporative cooling options to ameliorate the ill effects of local level warming. High-density development for shade creation must be developed in such a manner that it does not impede the positive effects of natural areas in the city. Air paths and breezeways need to be either maintained or introduced to create such possibilities.

- Characteristics of variables do not vary significantly in relation to the orientation of the sites on the banks of the lake.

Conclusion

The study is a reasearch initiative to ascertain the effects of a urbanwater body on the thermal comfort, relative humidity and the wind speed in the immediate environs of its siting. The 'Beira Lake' in warm humid Colombo was chosen as case study.

The simulated results and analysis were limited to the peak time of the day of 14.00hrs of a single day in March.
Research concludes that for the peak time of the day;

- An urban water body has a negative effect on the immediate environs as opposed to a vegated area of similar magnitude.

- Positive aspects are seen in the wind speeds it maintains and/or induces.

- High Density bulding fabric has advantages only for the areas in close proximity of the buildings. They adversely effect the overall wind speed and evaporative cooling potential of natural areas in the city.

Future research needs to encompass the effects of such natural areas in the city such as the Beira Lake, for the complete hours of the day as well as distinct times in the year, thus, allow for a wider base of data and better analysis.

The challenge of future research and its application is to deepen the knowledge in relation to established urban interventions and strategies in general and urban water bodies in particular, yet draw upon the unique microclimatic context of Colombo, Sri Lanka.

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