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Local measures to mitigate the urban heat island effect in hot and humid climate: Comparative case study of Sana'a, Bushehr and Dubai Marina

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Abstract

Cities experience the effect of extra heat compared to their rural surroundings. This phenomenon is known as the Urban Heat Island (UHI) effect. Urban geometry, land cover, landscape and metabolism have been cited as the main contributors to the UHI effect. This paper compares the UHI mitigation strategies of the contemporary development of Dubai Marina (United Arab Emirates) with historical cities of Sana'a (Yemen) and Bushehr (Iran). Shadow patterns, wind flow, vegetation ratio, surface materials and energy consumption are being investigated to measure their effectiveness on microclimate moderation in hot and humid climate. The study benefits from aerial imagery feature extraction, climate data and spatial measurements as primary sources. An analysis chart based on Strengths, Weaknesses, Opportunities and Threats (SWOT analysis) is being used to facilitate discussion about future development in Dubai Marina. Results indicate that increasing the use of permanent shadow, natural ventilation, permeable materials and vegetation can contribute to mitigate the UHI effect, while the use of surface water, car-oriented transport networks and free standing buildings can magnify the UHI effect in hot and humid climates. The outcome design guidelines can be used in cities in hot and humid climate, which intend to mitigate the UHI effect.

Keywords: Urban Heat Island effect; Hot and Humid Climate; Shadow Pattern; Urban Vegetation; Land Cover

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1. Introduction

Almost all the expected population growth by 2050 will be absorbed in urban areas (DESA, 2012; Koolhaas, 2000). Such an increase of urbanization has been magnifying in developing countries where cities are envisaged to accommodate over 50 percent of the global population in the next four decades (an additional 1.4 billion for Asia, 0.9 billion for Africa and 0.2 billion for Latin America) (Satterthwaite, 2007). Concentration of the fast urbanization in developing countries means higher densities in existing cities and more new cities to accommodate such a significant population growth. Instant cities in developing countries are the result of such a high demand for spatial development (Gubitosi, 2008). However, the speed of spatial development in fast growing cities tends to overlook environmental and social aspects of urban life in many cases including Dubai Marina. A considerable amount of natural landscape transforms to building mass and hard surfaces, which highlights environmental issues of instant cities.

Up to 80 percent contribution of cities to global CO2e emissions (UNECE, 2011) is expected to increase the mean global surface temperature up to 2 degree centigrade by 2050 (OECD, 2010). Such a change is likely to have a severe impact on natural ecosystems and human behaviour in cities, including public health and public life (Guest et al., 1999; Stone, 2012). Increase of urban surface temperature will also accompanied by changes in local precipitation, evaporation and wind patterns (Australian Bureau of Meteorology, 2008; CSIRO, 2007), which can cause complex microclimate variation in regional scale of cities.

Urban areas, in addition, experience an additional heat increase (especially in summer time), known as the Urban Heat Island (UHI) effect. This additional heat storage is trapped in thermal mass of the built environment and can result in the city center being significantly hotter compared to the pre-urban surroundings, which reach frequently up to 4.5°C and peak at more than 10°C (Gartland, 2008). Such an additional heat can seriously suffer citizens' health and public life in developing cities.

This paper aims to compare the UHI mitigation strategies of historical cities of Bushehr (Iran) and Sana'a (Yemen) with the contemporary development of Dubai Marina (United Arab Emirates). Shadow patterns, wind flow, vegetation ratio and surface materials are studied to investigate their effectiveness on microclimate moderation in hot and humid climate. The outcome of this research is a set of design guidelines for developing cities in hot and humid climate to facilitate UHI mitigation in urban planning.

2. Background

The phenomenon of artificial heat in the urban settings has been documented first in the study of London climate in the early 19th century followed by a number of similar studies in Paris and Vienna (Gartland, 2008). However, more in-depth research on UHI effect and its major contributors have commenced only since the 1970s. Urban geographers and meteorologists are the very first contemporary scholars who have studied UHIs (Oke, 1978; Paterson & Apelt, 1989; Tapper, 1990). These large scale studies tend to document the phenomenon and contribute mainly to understand the behaviour of UHI by comparing city centres and their rural surroundings.

Alongside with meteorological research on UHI, scientific investigations on thermodynamics of surface materials study the energy exchange and heat balance in the built environment (Gartland, 2008; Harman & Belcher, 2006; Wang, Bou-Zeid, & Smith, 2011). Corresponding remote sensing methods including satellite-base, air-born and on-spot thermal photography improve the knowledge on how surface materials have influences on different layers of atmosphere during day and night. These investigations aim to model building energy flux based on material thermal specifications such as density, thermal capacity, convection, conductivity and reflection.

Recent extensive literature on the UHI effect indicates that the artificial increase of temperature in cities is happening because of large-scale changes in energy and water balance in the built environment (Erell, Pearlmutter, & Williamson, 2011; Gartland, 2008; Oke, 2006; Santamouris & Geros, 2006). This artificial temperature increase affects microclimates in different layers of atmosphere including Surface Layer (buildings and land surfaces), Canopy Layer (below the canopy of trees and in human scale) and Boundary Layer (up to 1500 meters above the ground surface), which intertwine in complex climatic systems (Gartland, 2008). Local wind patterns and air circulation in the built environment can moderate the UHI effect and mix the air in each layer with other adjacent layers (Erell et al., 2011). Oke (1988, 2006) argues that the UHI effect is a complex procedure corresponding to four major contributing factors:

- Urban geometry alters heat balance in the built environment by affecting shadow patterns. It affects the patterns of materials' exposure to sunlight and the heat storage in building mass. The complex heat radiation exchange between building-mass and adjacent atmosphere can also change the intensity and patterns of air-flow in urban canyons.
- Urban cover and surface materials' thermodynamics affect the heat absorption and reflection time-rate in the built environment. Colour, texture, transparency and distribution of materials and their exposure to sunlight can alter the heat flux in outdoor space in complex procedures.
- Urban vegetation and the modification of natural landscape affect water and heat exchange balance in the built environment. Photosynthesis and evaporation process in urban vegetation contributes to decrease the ambient temperature in pedestrian level. Urban greenery types, distribution and intensity also affect lower atmospheric air-turbulence.
- Urban metabolism and anthropogenic (human made) waste heat in cities, which is mainly related to mass energy consumption for indoor air conditioning and car-oriented transport systems.

Existing approaches to the UHI effect are more likely to focus on large scale monitoring and mitigation strategic planning in city scale rather than smaller scales of the built environment in which the phenomenon is more sensible. The few existing UHI studies in canopy layer from the eyes of participants have been affected strongly by adaptive human outdoor comfort theory which itself is a new field of study (Nikolopoulou, Baker, & Steemers, 2001; Steemers & Steane, 2004; Szokolay, 2008).

Alongside cities' substantial energy consumption and concomitant heat production, public life in most metropolitan areas is increasingly suffering from the UHI effect during summer nights, when night-cooling is not effective at pedestrian level. Qualities of outdoor space and cost-benefits of existing mitigation strategies need to be more focused in UHI research to lead the corresponding scientific results towards implementation.

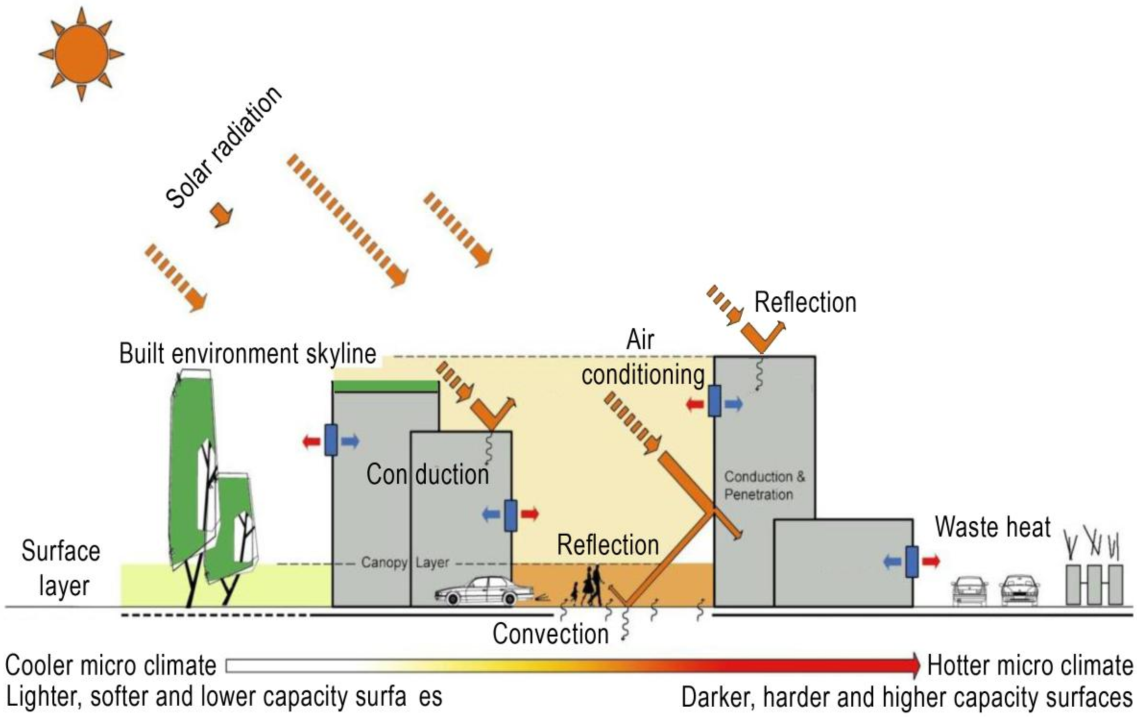

Figure 1. Urban geometry, land cover, landscape and metabolism are contributing to the Urban Heat Island effect

The UHI effect behaviour varies in different climates (Oke, 2006; Thatcher & Hurley, 2012; Wong & Yu, 2008). Although the major contributors may still be affective in every climate, the level of effectiveness and related mitigation strategies are highly contextual, which highlight the need for further comparative case studies and climate specified UHI research.

3. Methodology: Comparative case analysis

This case study is built upon the background literature on UHI effect. It investigates the effect of urban structure (shadow and wind patterns), urban cover (material choices and surface water), urban landscape (vegetation type and ratio) and urban metabolism (air-conditioning and transport) on mitigation of the UHI effect in hot and humid climates.

A developing district of Dubai Marina is being compared to two historical cities of Bushehr (Iran) and Sana'a (Yemen), investigating the effectiveness of their vernacular UHI mitigation strategies in hot and humid climate. This comparative case study is using aerial and on-spot photos, observation and measurements as its primary resources. Analytical maps, diagrams and models are drawn upon the primary resources to study shadow patterns and wind flow in the selected sites. The special ratio is calculated based on the ratio between height and width of the space (H/W ratio), which is common in UHI effect studies.

Vertical aerial photos are being analysed by Feature Extraction Method to calculate the quantities of vegetation, land cover and spatial ratios. The study is using available materials' thermal specification and climate data as its secondary resources. Complex scientific calculations are simplified to key factors to be as communicative as possible to urban planners and policy makers (appropriate references are cited during discussions).

The UHI effect is studied at the critical 21st of June, which is theoretically pointed as the hottest and longest day of the year in northern hemisphere. A qualitative analytic chart based on Strengths, Weaknesses, Opportunities and Threats (SWOT) is being used to further quantitative comparisons towards strategic discussions. The outcome of this research is a set of design guidelines for developing cities in hot and humid climate, which aim to mitigate UHI effect.

3.1. Urban space and climate conditions

Dubai is a well-known example of an 'instant city', having developed from a pre-industrial village to a post-industrial megacity in less than 50 years (Damluji, 2006; Gubitosi, 2008; Lehmann, 2008a; Pacione, 2005). Dubai Marina is a new canal-base urban district, stretched 3 kilometres along the Persian Gulf southern shoreline. It is designed to accommodate up to 120,000 dwellers in freestanding residential and hotel towers (200 skyscrapers, mostly have more than 20 stories). The concept of maximum water front development by designing an artificial canal shapes a large open space which covers 40 percent of the whole site (0.5km2 water way and 0.6 km2 landscape features). However, the significance of this public space is under the shadow of high demand of energy, inappropriate surface materials and site layout which raise the concern for public life in Dubai Marina. Public spaces in Dubai are permanently warmer than human comfort preferences in hot and humid summer time.

Dubai, Sana'a and Bushehr have hot and humid climate especially during the summer time, but limited annual rate of precipitation. The fast track development of Dubai has been commenced since 1967 (Pacione, 2005), whilst Sana'a and Bushehr urban fabrics are the result of gradual development (Memarian, 1996) in which local dwellers gradually improve vernacular construction strategies to manipulate materials and forms to mitigate summer heat and humidity in the built environment. High air temperature (more than 40°C) and relative humidity (more than 70%) in the selected sites in summer time make them appropriate targets to study UHI effect.

Land Use: Mixed
Built land Cover Ratio: 20%
Built Height: 20-40 Stories and more
Residential Population: 120,000
District Area: 4.4 Square Kilometres (Damluji, 2006)

Land Use: Mixed
Built land Cover Ratio: 60%
Built Height: 5 to 9 Stories
Residential Population: 50,000
District Area: 1.5 Square Kilometres (Pini, 2008)

Land Use: Mixed
Built land Cover Ratio: 50%
Built Height: 2 and 3 Stories
Residential Population: 8,000
District Area: 0.6 Square Kilometres (Gazbanpoor, 2000)

Figure 2. Urban structure in Dubai Marina, Sana'a and Bushehr

Table 1. Climate condition and heat stress in three cities (www.weatherspark.com, 2012)

Annual Average	**Dubai**	**Sana'a**	**Bushehr**	Surface Temperature Increase Projection for 2050 = 3-5 °C for all three cities (Hansen et al., 2002)
Average High (°C)	33.4	26.8	29.4	
Record High (°C in June)	48	41	45.2	
Average Low (°C)	22.3	11.3	19.4	
Record Low (°C in January)	7	0	10.6	
Precipitation (mm)	88.6	198.5	228.5	
Relative Humidity (%)	26-92	12-75	34-88	

3.2. Shadow patterns

Due to the permanent high temperature and humidity during the hot and long summer days, sunshine is not pleasant in public space in hot and humid climates (Afshari, 2012; Dahl, 2010; Givoni, 1998; Gobadyan, 2003). In Sana'a streets and squares are surrounded by traditional tower buildings (Pini, 2008) with an average of 15 meters height (up to 30 meters). Based on generally 3-10 meters of street width and maximum 30 meters of square length, the H/W ratio varies from 2/1 up to 5/1 at the street level, while 1/2 and 1/1is more practiced in the public square. Urban structure in Sana'a provides permanent shadow at least 6 hours and 45 minutes a day over the public space, while other areas have reliable continuous partial shadow patterns.

In Bushehr streets and squares are surrounded by traditional buildings which also have central courtyards. Buildings' height regularly reaches 5 meters per story, which means 10 to15 meters height for a typical building in Bushehr (this allows hot air to rise in indoor space and let cross ventilation to naturally ventilate the space). Streets' width varies between 3 and 10 meters, courtyards' length does not exceed 15 meters and squares have maximum 30 meters length. The H/W ratio varies between 3/1 and 5/1 for streets, 1/1 in average courtyard and maximum 2/1for public squares. Urban structure in Bushehr provides permanent shadow at least 6 hours a day over the public space, whereas other areas have reliable continuous partial shadow patterns.

In the case of Dubai Marina building, height and layout cause more variation in H/W ratio. Some towers have more than 100 meters height, while Marina Mall rises up to 20 meters. Some high-rise blocks have only 50 meters distance from adjacent buildings, while many others keep the distance of up to 400 meters to nearest blocks. This causes H/W ratio varies between 2/1 and 1/20, which provides scattered shadow in most areas and makes some parts of public space shadow-free almost all daylong (which lasts 13-14 hours on 21 June). Furthermore, the free-standing skyscrapers do not provide continuous shadow on the pedestrian level in many cases.

3.3. Wind flow patterns

Wind flow can mitigate the UHI effect by transferring the warm air apart from hot surfaces of the built environment (Ashie, 2008; Erell et al., 2011; Paterson & Apelt, 1989). The effect of wind patterns in humid climates is more crucial, because it improve evaporation cooling (evapotranspiration) by improving the turbulence of humid air, concentrated near surfaces.

Due to relatively warm annual average temperature, air turbulence is desired almost all through the year and especially in hot summers of Sana'a, Bushehr and Dubai. Still, each case has its specific contextual constraints regarding to local wind patterns.

Sana'a has two types of regional winds: hot and sandy wind from North and North-East (desert wind), moderate wind from South and West (sea breeze) and cool wind from East (highland wind). Summer winds generally come from North-East, which are hot and dry in their essence (Lewcock, 1982, 1986). Direct entry of these winds into public space can magnify the hot temperature of June in Sana'a. City fortification (9-14m high) and compact urban form tend to divert the hot wind above the canopy layer of the city (Davidson, 1995). Air flow above the canopy layer causes an inverse pressure and sucks the heat and humidity out of the public space (Upper levels of tower-buildings are not under use during the day time).

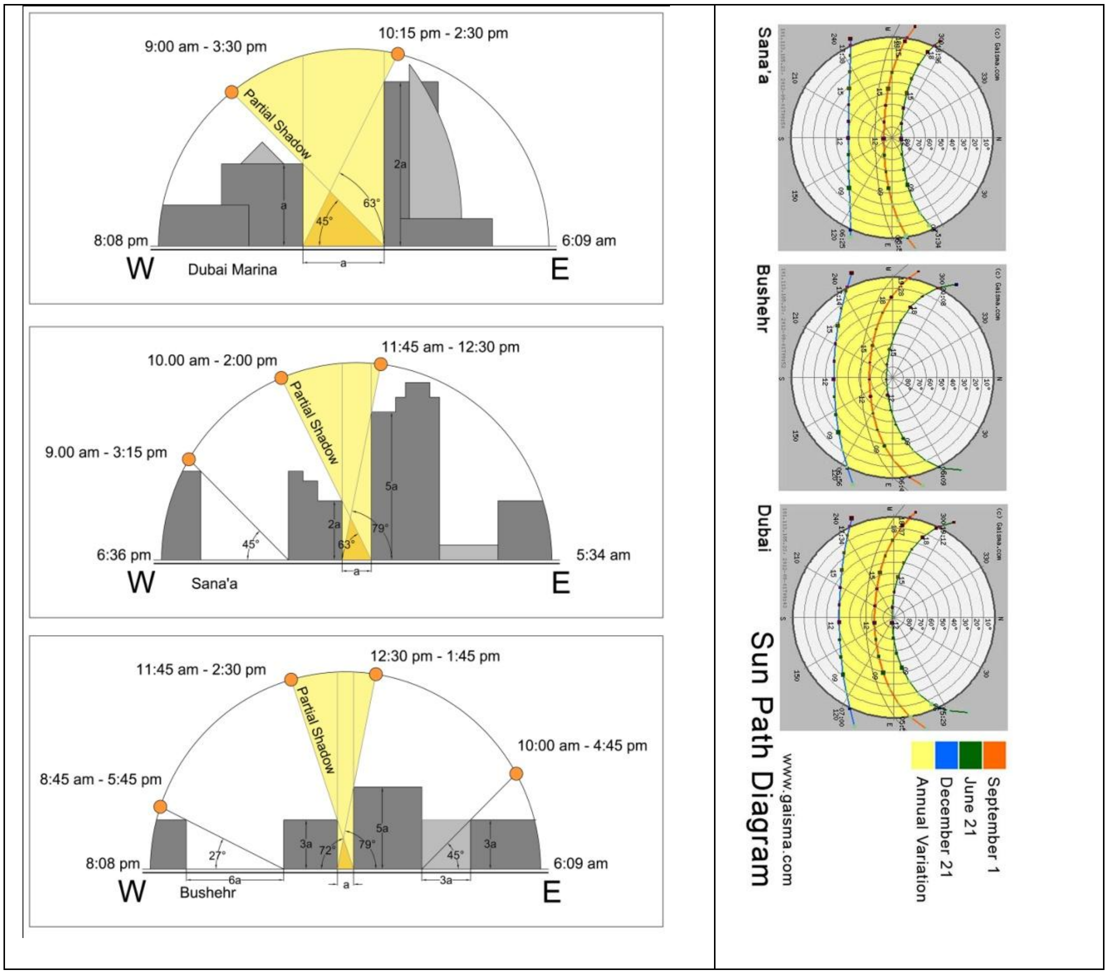

Figure 3. A typical South-North oriented public space in Sana'a and Bushehr has complete shadow during 11 out of 12 hours (out of 14) on a typical 21th June

Bushehr urban space is influenced by cool North wind (highland wind) and daily sea breeze coming from sea to coastal land at daytime (Memarian, 1996). The dominant summer breeze is the North wind. Maximum wind-flow is preferable in the public space of Bushehr. Every wall has numerous small openings to allow wind to flow over the city canopy layer, while balconies take advantage of pleasant wind in summer time (Giridharan, Ganesan, & Lau, 2004). High H/W ratio and shadow patterns help air flow to remain cool in the urban canyon of Bushehr.

The dominant wind in Dubai Marina comes from North-West which is cool sea breeze. However, another existing hot and sandy wind from Arabian Peninsula also affects the site (Böer, 1997). No particular consideration for preventing South-West wind (desert wind) has been observed in Dubai Marina.

Table 2. Shadow hours in Sana'a and Bushehr for a typical South-North oriente open space on a typical 21 June

Case (sunshine)	Space	H / W Ratio	Complete Shadow (hh:mm)	Partial Shadow (hh:mm)
Sana'a (13 hours)	Streetscape	2 / 1	9:00	4:00
		5 / 1	12:15	0:45
	Public Square	1 / 1	6:45	6:15
Bushehr (14 hours)	Streetscape	3 /1	11:15	2:45
		5 / 1	12:45	1:15
	Public Square	1 / 2	6:00	9:00
	Court Yard	1 / 1	9:15	4:45
Dubai Marina (14 hours)	Compact Built Area	2/1	9:45 Scattered	4:15
	General Built Area	1/1	7:30 Scattered	6:30
	Central Public Space	1/20	-	14:00

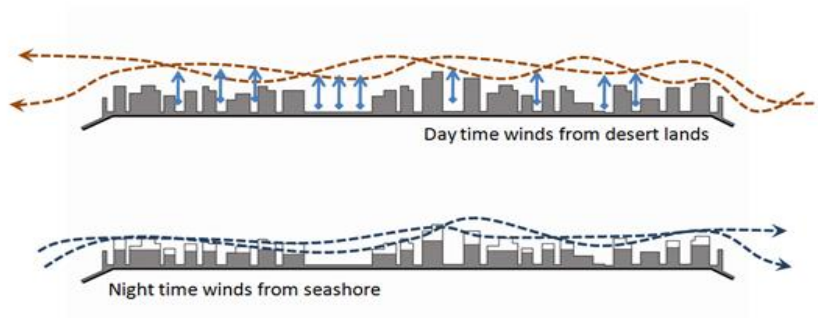

Figure 4. Diversion of Desert Wind Flow above the skyline of Sana'a due to compact urban form and city walls

3.4. Surface materials and surface water

Surface materials influence heat balance by affecting the overall rate of heat flux in the built environment (ASHRAE, 2004). Special heat capacity, conductivity and reflectivity (Albedo) of materials are the most effective factors, which can cause the built environment to store sunlight energy (heat) in thermal mass and to postpone the energy exchange process. Lighter colours, less conductivity and appropriate reflectivity are recommended by UHI scientific research (Ashie, 2008; Dahl, 2010; Erell et al., 2011; Oke, 1988; Wang et al., 2011).

Traditional tower-buildings of Sana'a use Limestone for ground floor walls to prevent soil humidity to affect the whole structure. In upper levels mud-brick is being utilized (Davidson, 1995), which has high specific heat capacity and relatively low heat conductivity. It does not represent an ideal material to mitigate UHI effect (such a material can postpone building-air thermal transfer to night time, and can cause discomfort at summer night time. But mud-brick is the most available vernacular construction material in Sana'a). As a mitigation strategy, the surface of mud-bricks is plastered with white ornamental shapes, which has made the distinctive character of Old Sana'a.

In the case of Bushehr, the dominant construction material is a vernacular Coral-stone. It is a permeable and relatively cool masonry material (in some cases it is covered completely with plasterwork in white colour). As a passive system, it works reliably enough to ventilate heat and humidity from the canopy layer (Indoor life in Bushehr and Sana'a has not been happing in ground floor). Ceilings, balconies, fences and opening frames are made of wood, which is the coolest natural material (see table 3). However, the use of wood in vernacular construction has limitations due to local availability in Bushehr.

Table 3. Thermal specifications for general construction materials in ascending order, based on contribution to the UHI effect (Oke, 1978)

	Thermal Conductivity (W/M°K)	Specific Heat Capacity (J/Kg°K)
Fibre Board	0.06	1000
Wood	0.14	1700
Water	0.57	4180
Dry Soil	0.3	800
Plaster Rendering	0.5	1000
Brickwork	0.6	800
Asphalt	0.75	800
Glass	1.05	500
Concrete	1.51	650
Stone	1.5	910
Steel	53.3	500

In Dubai Marina, dominant surface materials are steel, glass, stone and asphalt which are among non-preferable materials for UHI mitigation purposes. Moreover, free standing skyscrapers provide much more surface area compare to compact and continuous built form in Sana'a and Bushehr.

The vast central water canal is under permanent sunshine, which magnifies evaporation in hot and humid summer time of Dubai and causes discomfort in the public space. The use of surface water is not a practical objective in extra hot and humid climate of Dubai.

3.5. Urban vegetation and landscape

Vegetation and greenery can mitigate the UHI effect in two ways: first, through photosynthesis process, which uses the solar energy for greenery metabolism and second, through evapotranspiration process, which absorbs the ambient heat to evaporate the moisture from the surface of leaves (Erell et al., 2011; Gartland, 2008; Oke, 2006). The ratio of surface vegetation to total site area is 24% for Sana'a (including urban farms), 8% for Bushehr and 15% for Dubai Marina. However, consideration of urban (residential) density reveals a different result. Sana'a has 7.2 square meters urban greenery per capita, Bushehr has 6 square meters per capita, while Dubai Marina has only 5.5 square meters vegetation per capita. The character of urban vegetation is another considerable subject. Urban greenery includes a significant proportion of urban agricultural lands in Sana'a (over 80%). It locates mainly in private courtyards in Bushehr for climate moderation purposes, while focuses mainly on beauty in Dubai Marina.

Table 4. Urban vegetation ratio per capita and per plot in Sana'a is higher than Bushehr and Dubai Marina

	Precinct Area (km2)	Residential Population	Urban Density (person/km2)	Urban Vegetation Area (m2)	Vegetation/Urban Density (m2/person)	Vegetation/Land Cover (%)
Sana'a	1.5	50000	33300	360000	7.2	24
Bushehr	0.6	8000	13300	48000	6	8
Dubai Marina	4.4	120000	27300	660000	5.5	15

Highlighting the huge difference between high impact lifestyle in Dubai Marina and low impact traditional lifestyle in Sana'a and Bushehr (regarding to energy consumption and waste heat generation for air-conditioning and daily transport), Dubai Marina requires much more urban greenery to decrease its considerable environmental impacts.

3.6. Anthropogenic waste heat

Public space discomfort and high dependency to non-renewable energy consumption for transportation in contemporary urban districts (including Duabi Marina) cause a considerable amount of waste heat in cities

(Chen, Jiang, Zhang, He, & Zhou, 2009; Ichinose, Matsumoto, & Kataoka, 2008; Oke, 2006). This pushes citizens into air-conditioned buildings, creating an ever-increasing rise in outdoor temperatures. Research indicates that outdoor temperature increase can accelerate indoor energy consumption for air-conditioning (Giridharan et al., 2004; Priyadarsini, 2009). This makes a loop between waste heat and outdoor temperature increase.

In contrast with passive urban design strategies and walkablility in Sana’a and Bushehr, Dubai Marina is highly dependent on private car transportation and use of indoor air-conditioning. Lack of in-detail data regarding anthropogenic waste heat in selected sites do not conceal the overall fact that Duabi has one of the highest annual CO2 emissions with 25 metric tonnes per capita per year comparing to annual 7.4 for Iran and 1 for Yeman (2008 data from The World Bank website). Moreover, CO2 emission per capita is more than country-average for luxurious Dubai Marina, while is less than country-average in Sana’a and Bushehr old cities.

4. Discussion and SWOT analysis

Current research indicates a number of key UHI mitigation factors in hot and humid climates including shadow patterns, wind patterns, surface materials, surface water, urban vegetation and urban metabolism. Permanent shadow is desired in hot and humid summers of Dubai to mitigate UHI effect in pedestrian level (canopy layer). The maximum shadow tradition is particularly favoured in Sana’a and Bushehr. However, free-standing skyscrapers in Dubai Marina provide only temporary and partial shadow over the public space, which can magnify the summer heat in Dubai Marina.

Air-flow can also mitigate the UHI effect. It is well articulated in Sana’a and Bushehr, based on their regional wind patterns (natural ventilation by cool winds and spatial protection from hot winds). Site layout in Dubai Marina effectively allows sea-breeze to mitigate summer heat, but there is no particular design consideration to protect the site from desert-winds. This hot wind comes from south-west deserts in daytime can magnify the summer heat in Dubai Marina.

Building materials with low thermal conductivity, medium to high thermal capacity, light surface colours and permeable texture are utilized in traditional architecture of hot and humid climates, whilst surface water is not favoured due to high air-humidity in summer time. Dubai Marina provides a large amount of surface water, which is likely to be under the sunshine most of the day. This can provide discomfort in public space in hot and humid climate and push dwellers inside air-conditioned buildings.

Relatively low urban vegetation per capita, random vegetation typology and high dependency on car-transportation and air-conditioning cause anthropogenic waste heat to magnify the UHI effect in Dubai Marina. Based on the identified UHI key factors, table 5 represents contextual Strengths, Weaknesses, Opportunities and Threats (SWOT) in Dubai Marina regarding to UHI effect mitigation.

Table 5. SWOT Analysis of UHI mitigation Strategies in Dubai Marina

Strategy Type	Strength	Weakness	Opportunity	Threat
Shadow Patterns	Providing Permanent Shadow in compact areas	Scattered Shadow in built area	Shadow pattern improvement in pedestrian level	More urban density can cause more heat stress
		No shadow on a part of central public space	Connecting built forms with temporary elements	Large scale and costly change
			Solar energy generation	
Wind Patterns	Allowing Sea breeze in between built area	No specific design for desert wind avoidance	Diverting desert wind by more compact built form in South West side	More urban density can cause more heat stress
Surface Materials	Usage of light colours in landscape design and ceilings	Mass usage of dark and dense materials for facades	Increasing the amount of lighter and more permeable materials	Costs of change and management issues
	Replacing fast heating materials with greenery in some areas	High usage of materials with low Specific Heat Capacity and high Thermal Conductivity	Usage of wood, fibre fabrics and other materials with high SHC and low TC	Lack of interest in development sector due to global city competition
Surface Water	Providing alternative transport systems	No shadow over the surface water	Permanent shadow over the surface water in summer time	High humidity in hot summers can cause significant discomfort in public space
Urban Vegetation	Use of urban vegetation as surface material	Insufficient vegetation ratio per capita	Increasing the amount of urban vegetation on available surfaces such as green roofs and green walls	Financial costs of landscape change and maintenance issues
	Landscape design beauty	Low shadow and food providing vegetation	Increasing fruit trees and large canopy trees	Increasing air humidity and costs of maintenance
Urban Metabolism	Connections between buildings in more compact areas	High energy use for transportation and indoor air-conditioning	Increasing the use of natural ventilation	Behavioural change strategies need long time for implementation
			Improving walkability and outdoor thermal comfort	

5. Conclusion

Dubai Marina high dependency to private car transportation and air-conditioning, fast rate of urban development, numerous ambitious construction projects and increasing indoor urban life make it a vulnerable target of microclimate change and UHI effect.

Vernacular Climate Sensitive Urban Design in Sana'a and Bushehr underlines the importance of maximum shadow patterns, sensitive consideration of wind patterns, light and permeable surface materials and maximizing urban vegetation to mitigate the UHI effect in public space. As such, the following guidelines are proposed to mitigate UHI urban development projects in Dubai Marina and similar hot and humid urban precincts:

- Increasing permanent and continuous shadow over the public space to decrease the exposure of surface materials to sunshine in summer time
- Designing Wind Sensitive public spaces based on local wind patterns to moderate the UHI effect in summer time

- Increasing the use of Light (colour) and permeable materials with high Specific Heat Capacity and low Heat Conductivity in public space (e.g. wood and fibre board)
- Avoiding the use of large amount of surface water without providing appropriate shadow
- Maximising the ratio of urban vegetation per capita to mitigate anthropogenic waste heat in public space
- Improving walkability of public space and natural ventilation to decrease carbon emissions of developing urban precincts

Population and building density are inevitable involvement of urbanisation. Crucial is to understand the possibilities for transformation of existing urban fabrics towards more liveable and sustainable future (Bosselmann, 2008; Bosselmann, Arens, Dunker, & Wright, 1995; Lehmann, 2008b, 2010). The matter of microclimate moderation needs to be highlighted in fast developing cities such as Dubai Marina, which in many cases can be implemented by sensitive spatial transformation of existing structures.

6. Research limitations and further opportunities

Current research is limited by data availability for the selected sites. Further studies can also benefit from remote sensing thermal photography and GIS data. The comparison between UHI effects in the three selected sites provides observational and model-base analysis. In order to move towards more certainty about the research outcomes remote sensing thermal photography and on-the-spot micro climate measurement are required.

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