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THE ROLE OF SIMULATION IN URBAN DESIGN DECISIONS: MICROCLIMATE AND HUMAN COMFORT CONSIDERATIONS IN PLANNING

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Abstract

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Keywords

Simulation; Human Comfort; Urban Design; Environment; Microclimate

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INTRODUCTION

The microclimate of urban open spaces is influenced by several parameters such as the urban form and geometry, urban density, the vegetation, the water levels and the properties of surfaces (Shishegar N, 2013). Both physical and climatic factors are combined in order to achieve sustainable human thermal comfort conditions. On the other hand Al Mahmoudiya Canal has been a focal issue for all Alexandria's Governorate plans for the past 40 years. Never has there been a plan considering microclimatic conditions which has direct impact on human comfort.

This paper reviews the outdoor thermal conditions by the design of enough open spaces, proper paving, vegetation and water levels and set priorities by means of comparing current, predicted and proposed urban designs in order to modify current legislative planning and building measures. The paper's goal is to enhance the understanding of simulation tools and decision making in order to maintain and preserve well designed old historic areas in collaboration with microclimate and outdoor human factor issues. The specific aim of the study is to enhance current planning sprawl conditions in a sample of the old district at Kom Al Shoqafah by Al Mahmoudiya Canal and compares it to predicted urban design of the same area considering microclimatic conditions as well as comparing it to proposed designs by use of a simulation tool to help make decisions about legislative measures that could enhance human thermal comfort.

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ISSUES

Simulation

The context and objectives for urban modeling have grown far more complex over the years. Urban model development combine to shape the needs in ways that are sensitive to a range of land use and transportation policies and their interactions, that build on clear and defensible foundations in behavioral theory, and that facilitate participation in the testing of alternative policy strategies and their evaluation" (Waddell P. et al,, 2004). Sophisticated simulation systems such as UrbanSim and other models the long-term impacts of transportation and land-use alternatives. Accounting for human values throughout the design process helps in designing interactions that engage both planners and citizens in the decision-making process. Recently modeling has participated in almost all features of urban design tools.

Urban Design

Urban design is the process of designing and shaping cities, towns and villages. Urban design addresses the larger scale of groups of buildings, streets, public spaces, neighborhoods, districts, and entire cities. Urban design is the proactive design of urban areas. It focuses on the design, quality, character and appearance of places, including buildings and the spaces between them. Urban design is concerned with so many aspects. According to Erell (2011) it is concerned with pedestrian zones; incorporation of nature within a city; and aesthetics. It is also concerned with the urban structure; urban typology, density and sustainability; spatial types and morphologies related to intensity of use, consumption of resources and production and maintenance of viable communities. Urban design is also concerned with accessibility; legibility and way finding; animation; function and fit; complementary mixed uses; character and meaning; order and incident; continuity and last but not least civil society.

Urban design is not just to produce an idealized plan derived from climatic considerations, but it also involves producing a workable plan that is economically viable and accepts that the planner must consider other factors, such as the requirements of transportation systems. (Mills, 2006) noted that "while the meteorologically ideal settlement serves a useful pedagogical purpose, it does not recognize planning realities where climate issues are rarely a dominant concern".

Decision Making

Currently in Egypt the planning framework at various levels of governance influence the urban planning process. Development plans and policies are prescribed by central government, implementation is however the responsibility of local government. According to the law 119/2008, there are four main levels of urban planning in Egypt. These four levels include national spatial planning; regional spatial planning; governorate spatial planning; and local spatial planning. According to Urban Planning in Egypt national includes the whole country; regional consist of seven regions; there are 28 governorates; at local level there are 218 cities and 4200 villages (Hegazy I., 2010).

Urban Microclimate

Climate is the long term behavior of the atmosphere in a specific area, with characteristics such as temperature, pressure, wind, precipitation, cloud cover and humidity etc. An urban area is an area with a high density of human created structures in comparison with the areas surrounding it. A microclimate is a local atmospheric zone where the climate differs from the surrounding area. The term may refer to areas as small as a few square meters (for example a garden bed) or as large as many square kilometers. Microclimates exist, for example, near bodies of water which may cool the local atmosphere, or in heavily urban areas where brick, concrete, and asphalt absorb the sun's energy, heat up, and reradiate that heat to the ambient air: the resulting urban heat island is a kind of microclimate.

Human Comfort

Human comfort depends primarily upon thermal comfort. There are six primary factors that directly affect thermal comfort that can be grouped in two categories: personal factors - because they are characteristics of the occupants - and environmental factors - which are conditions of the thermal environment. The former are metabolic rate and clothing level, the latter are air temperature, mean radiant temperature, air speed and humidity. Even if all these factors may vary with time, standards usually refer to a steady state to study thermal comfort, just allowing limited temperature variations. (en.wikipedia.org, 2015). Air temperature is also governed by solar radiation.

Air movement depends on air pressure. Humidity, if high it reduces evaporation rates. Exposure to radiant heat or cool sources can affect thermal comfort. What we experience and feel relating to thermal comfort in a building is related to the influence of both the air temperature and the temperature of surfaces in that space. The mean radiant temperature is expressed as this surface temperature and is controlled by enclosure performances. Maintaining a balance between the operative temperature and the mean radiant temperature can create a more comfortable space.

The air temperature determines the rate at which heat is lost to the air by both convection and evaporation. That depends on the difference in temperature between the skin and the surrounding air (Bradshaw.2006). All bodies facing an air space or a vacuum emit and absorb radiant energy continuously. Hot bodies lose heat by radiation because they emit more energy than they absorb (Lechner.2001). Air movement across the body has a significant effect on the evaporation process of moisture from the skin and also has effect on heat loss. It accelerates the heat flow to and from the body by both convection and evaporation, thus it produces a cooling effect. A breeze of around 50cm per second provides an equivalent temperature reduction of around 3ºC (Silver. and McLean.2008). A measure of the moisture content of the air, the amount of moisture actually held by the air compared to the maximum amount that could be held at the same temperature, expressed as a percentage. For human comfort, relative humidity should be between 40 per cent and 70 per cent (Silver. and McLean.2008).

URBAN DESIGN ENHANCEMENT METHODS FOR THERMAL COMFORT

There are several urban microclimate moderation approaches. Parameters such as air temperature mean radiant temperature, relative humidity, and wind velocity can be modified by the effect of urban interventions, which thus may enhance the outdoor thermal comfort conditions.

Cool Reflective Materials

The use of high reflective material having the ability of reflect incoming solar radiation in urban environments is an effective technique to reduce the effects of the thermal environment on pedestrian comfort (Setaih et al., 2013). High albedo materials which were white and light colored surfaces were found have a significant improvement effect on thermal comfort (Levnson.2007).

Water Surfaces

Water features have always improved the pedestrian thermal comfort level by reducing air temperature in hot urban built environments. Researchers in Japan (Nishimura et al. 1998) have tested this concept by altering the temperature in both hot and humid urban spaces and confirmed usefulness of water facilities.

Green Spaces and Vegetation

One of the great advantages of planting and tree cover is the cooling affect that results from the joint impact of evapotranspiration and canopy shading (Setaih et al. 2013). Vegetation is a common and effective method to improve the outdoor pedestrian thermal comfort condition. Increasing green spaces in urban areas represents a significant mitigation technique in heat stress relaxation.

Building Arrangements with Wind Movement

Good design of urban fabric with air movement can reduce the effect of thermal environment, as this can control the wind direction and speed. Wind induced pressure distributions depend on many factors in urban environments. Building height, approach-flow, wind direction, urban geometry of buildings and their surroundings are factors that can induce wind velocity.

SIMULATION TOOLS IN URBAN DESIGN DECISIONS

Recently urban design processes are driven by market forces that respond to housing demands. Using computerized predictive tools that produces quantitative results on the effect of proposed designs upon climate is an important measure in facing decision makers that downgrade the importance of climatic consideration in urban design. Authorities should consider these quantitative measures that enables individual buildings to make better use of ‘natural energy’ and enhances the potential for pedestrian comfort and activity in outdoor spaces (Erell. et al, 2010). To define such measures urban planners need information on the micro climate situation in their city.

There are numerous simulation tools related to urban design from them UrbanSim, GIS, Envi-met and others. Each simulation tool focuses on a specific area for instance UrbanSim is concerned with metropolitan land use, transportation, and environmental planning, as for Envi-met it is concerned with surface-plant-air interaction inside urban environments. All simulation tools have the advantage of an unlimited number of points from the model which can be analyzed, whereas in a measurement study, only the results derived from the measured spots are reliable.

Evaluation of urban design should take into account complex and realistic scenarios, if necessary using computerized predictive tools. In the absence of quantitative studies on the effect of proposed designs upon climate, and on the basis of well-documented evidence from other planning professions, decision makers in general tend to downgrade the importance of climatic considerations in urban planning. The integration of climate analysis in the design process must be as early as possible, before possible avenues are blocked off by uninformed decisions. Appropriate climatic strategies can rarely be applied retroactively to correct errors made in the initial stages of the design. In order to apply urban climatology effectively in the process of town planning, a comprehensive approach must be adopted, balancing diverse considerations such as pedestrian comfort and building energy savings (Erell. et al, 2008).

The success of a project is often evaluated by its short-term economic return to the developers, so climatologists must be able to collaborate with other members of the design team to assess the economic effects of their recommendations on matters such as street width or building height, which may have significant economic implications. However, any evaluation of long-term sustainability should also take into account environmental effects. The best advantage is through simulation which gives predictive results that facilitates long term decisions.

CASE STUDY:

In order to investigate the local microclimate (air temperature, mean radiant temperature, air speed and humidity) in the climate region of Alexandria, Egypt simulation were run on the historical zone of Kom Al Shoqafah by Al Mahmoudiyah Canal west of Alexandria as a proposed area (Figure 1). Simulation was run three times concurrently. Readings of the microclimatic parameters were run consecutively currently, expected and proposed then compared on each indicator.

Materials & Method

ENVI-met is unique in the sense that it couples the atmospheric fluid dynamics model to a variety of different models such as a soil model, a radiation model and a vegetation model (Jean V. et al., 2012). ENVI-met 3.0 was chosen as a simulation tool because of its reliable results that was tested by previous researchers (Bruse et al., 2012). The programme uses a three-dimensional computational fluid dynamics and energy balance model (Bruse, 2009). The model has a high spatial and temporal resolution enabling a detailed study of how the microclimate varies within the studied space over time. The model includes simulation of flow around and between buildings; exchange processes of heat and vapor at the ground surface and at walls; turbulence, exchange at vegetation and vegetation parameters; bioclimatology and particle dispersion. Its calculation includes shortwave and longwave radiation fluxes from building systems and vegetation; transpiration, evaporation and sensible heat flux from vegetation; surface and wall temperature; water and heat exchange inside the soil; calculation of biometeorological parameters like Mean Radiant Temperature (MRT) or Predicted Mean Vote (PMV) Value; and dispersion of inert gases and particles including sedimentation of particles at leafs and surfaces.

The model gives a large amount of output data at atmosphere, heat flux and soil levels. Atmosphere includes Wind Flow, Wind Speed, Relative Pressure Perturbation, Wind direction, Potential Air Temperature, Specific Humidity, Radiation, Sky-View-Factor, Temperature, PMV Value. Heat Flux includes Ground Surface Temperature, Specific Humidity of Surface, Latent Heat Flux, Soil Heat Flux, Radiation of all surfaces, Surface Albedo. As for Soil temperature, water content and relative wetness of soil are compared to saturation values. As an urban design planner Mean Radiant Temperature, Surface Temperature, Relative Humidity, and Wind Speed of the Atmosphere was utilized in the study due to the direct impact they have on human thermal comfort. Parameters such as cool reflective material, water surfaces, green spaces and vegetation, as well as building arrangements are samples of design tools that directly affect human thermal comfort and in turn help in saving energy.

In urban design human comfort in pedestrian zones is of high importance. Alexandria which is considered a hot arid zone thermal comfort is one of its major challenges. Natural environmental solutions can reduce energy consumption which is of great importance in decision making. Thermal comfort environmental indicators (mean radiant temperature, surface temperature, relative humidity and wind speed) were chosen for the study due their strong impact on humans and on the other hand microclimate. The indicators chosen from the software were found to be of direct impact on the four enhancement methods chosen for the study. Micrometeorology measurements were taken in the beginning of the summer period on the 21 of June at 9.00 am. At this time of the year there are more pedestrians because of the summer vacation and before severe hot weather in August were habitants mostly move to summer resorts elsewhere.

The study was made on a sunny day in summer with no cloud coverage and air temperature of up to 30°C in 2m above ground and wind speed in 10m above ground varying between 1 and 3.5m/s. Readings of sample points of four categories were taken and average readings were recorded for the four categories which were waterfronts, main streets, secondary streets, and open spaces between buildings. The input data used in this study included meteorological data from reliable computational sources. The input data for the simulation model contained the physical properties of the studied urban areas (buildings, waterways, soil and vegetation) and limited geographical and meteorological data.

Description of the Site

Alexandria is the second largest city and the second largest metropolitan area in Egypt after Greater Cairo by size and population, extending about 32 km along the coast of the Mediterranean Sea in the north central part of the country. It is also the largest city lying directly on the Mediterranean coast. Alexandria is Egypt's largest seaport. In addition to its important Mediterranean Sea on the northern border Al Mahmoudiyah canal passes by its south linking the river Nile to the Mediterranean Sea. The study area is south of an important monumental historic area where the old town of Alexandria existed (Figure 2). The current condition is that many old factories existed due to their close location by the canal, train and port. Although only few of them are still working as a result of demolish of the nonfunctioning to the old transportation routes instead slums are found on the north and economic housing on the east sides. Old public buildings such as schools, hospitals were still functioning in the study area.

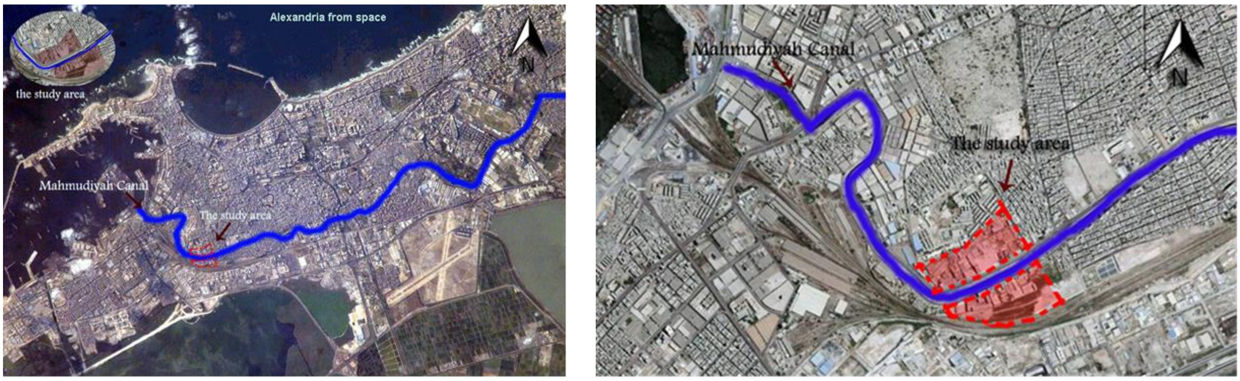


Figure 1: Historical Zone of Kom Al Shoqafah by Al Mahmoudiyah Canal West of Alexandria.

Current

Proposed Design (10 meters)

Proposed Design (36 meters)

Figure 2: Urban Design

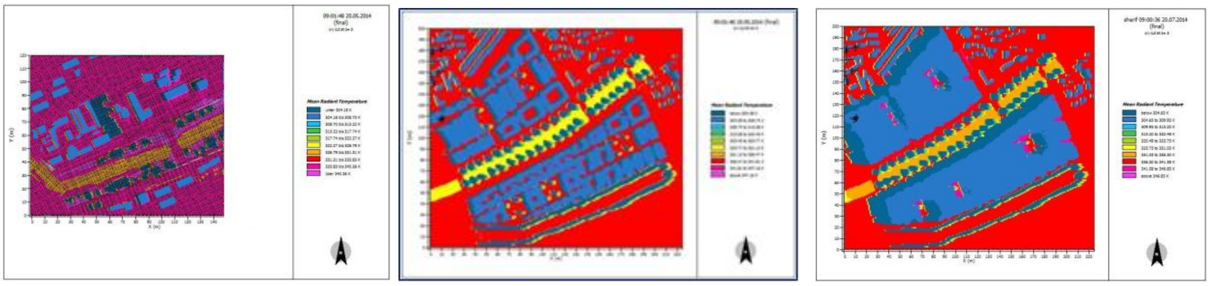
Site Modelling

The aim of the paper is to compare current, proposed Design 1 (10 meters height) adding intervene elements to enhance human thermal comfort in addition to microclimate and a proposed Design 2 (36 meters height) that applies current regulations of the proposed design (Figure 3,4,5 & 6) and (Table 1).

ITE	PROPOSED DESIGN 1	PROPOSED DESIGN 2
Location:	29°53'48.54" East/ 31°10'43.72" North 29°53'30.18" West/ 31°10'28.01" South	29°53'48.54" East/ 31°10'43.72" North 29°53'30.18" West/ 31°10'28.01" South
Climate Region:	Hot Arid	Hot Arid
	Alexandria is classified under hot arid climates, with high humidity at few days around the year.	
Building Types:	Industrial/Educational/Residential	Residential
Total Area:	Area = 134214.8080, Perimeter = 1649.5269	Area = 134214.8080, Perimeter = 1649.5269
Buildings Footprint:	55%	60%
Ground Cover (%):	35%	15%
Greens (%):	10%	25%
Water Surfaces (%):	(10%)	10%
Goal:	Pedestrian comfort in outdoor space.	Pedestrian comfort in outdoor space.

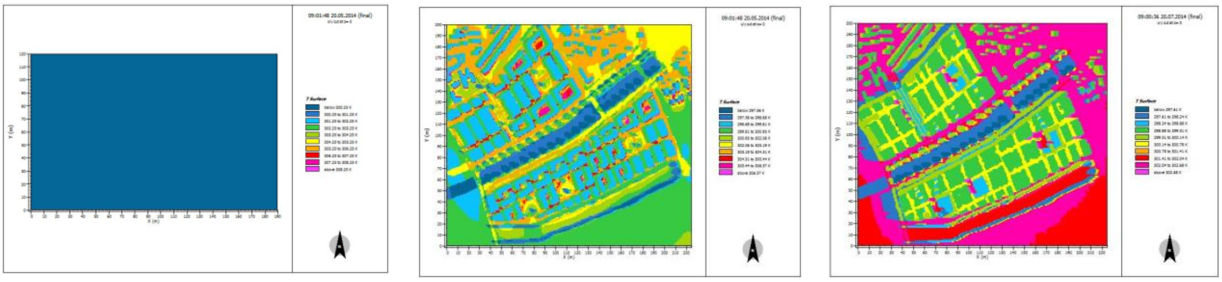
Table 1: Description of the Site Designed.

(Source: Authors)



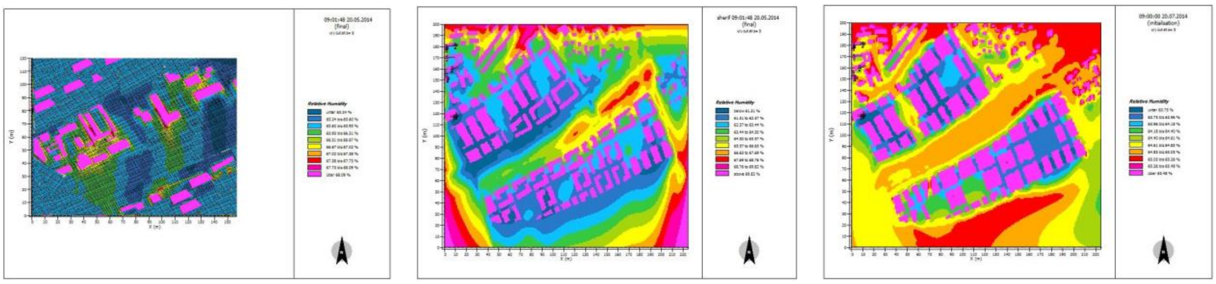
Current Proposed Design (10 meters high) Proposed Design (36 meters high)

Figure 3: Mean Radiant Temperature MRT



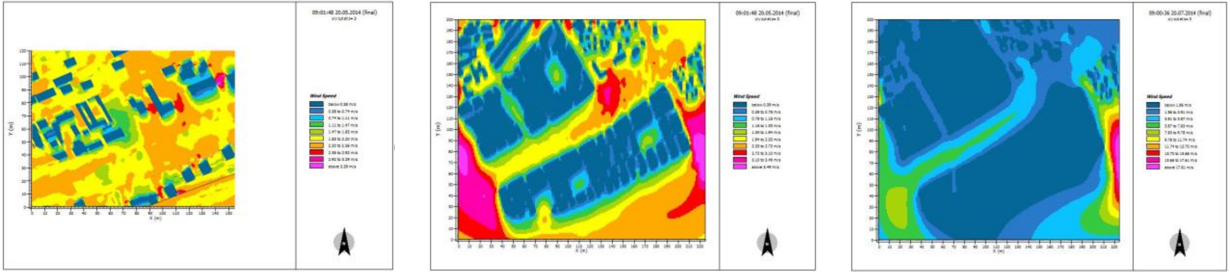
Current Proposed Design (10 meters high) Proposed Design (36 meters high)

Figure 4: Surface Temperature



Current Proposed Design (10 meters high) Proposed Design (36 meters high)

Figure 5: Relative Humidity RH



Current Proposed Design (10 meters high) Proposed Design (36 meters high)

Figure 6: Wind Speed

Baseline Area Modelling

Table 2 shows the baseline for human comfort limits for Mean Radiant Temperature, Surface Temperature, RH and Wind Speed that is suitable for human comfort according to the Egyptian energy codes for housing.

PARAMETER	VALUE
Mean Radiant Temperature	294.9-303.15K
Surface Temperature	294.9-303.15K
Relative Humidity	20%-50%
Wind Speed	50cm/sec-150cm/sec

Table 2: Baseline of Human Comfort Ranges for Indoor Housing According to Egyptian Energy Codes.
(Note: Celsius degrees [C] = Kelvin degrees [K]-273.15)
(Source: Authors)

Simulation Results and Discussion

Although differences are small and mostly out of comfort range but there are no baseline for outdoor microclimate in the Egyptian Energy Code of residential buildings. Table 3 gives us a brief recording of the results.

	WATERFRONT			MAIN STREETS			SECONDARY STREETS			OPEN SPACES BETWEEN BUILDINGS			INDOOR BASELINE
	Cur.	10m	36m	Cur.	10m	36m	Cur.	10m	36m	Cur.	10m	36m	
MRT	337	337	332	335	338	330	335	337	329	336	338	330	295-303k
ST	300	299	299	301	302	300	301	301	300	301	301	300	295-303k
RH	65	66	64	66	67	65	66	64	65	65	64	65	20-50%
Wind Speed	2	2	4	2	2	4	2	1	3	1	2	3	1-2 m/sec

Table 3: Comparison between the Three Designs on the Four Parameters to Indoor Baseline.
(Note: Celsius degrees [C] = Kelvin degrees [K]-273.15)
(Source: Authors)

As can be seen from Figure 7 mean radiant temperature was best in the 36 meters high design. Secondary streets had more impact than main streets and outdoor spaces. Least impact was on water front. Results as can be seen from Table 3 were all higher than the comfort range.

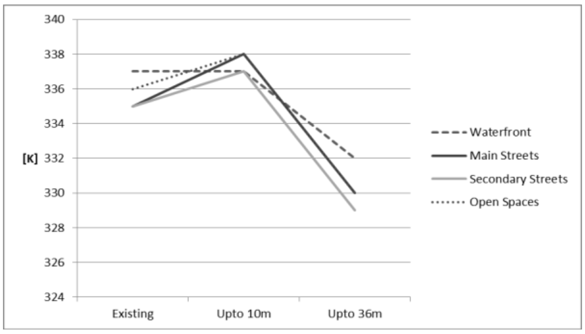


Figure 7: Comparison between the Mean Radiant Temperatures of the Three Designs in Terms of Human Comfort.
(Source: Authors)

From Figure 8 as can be seen surface temperature had again best in the 36 meters high design. Best results were on waterfronts. Main streets, secondary streets and open spaces between buildings had the same results. All results according to Table 3 were in the comfort zone though reference was of indoor baseline codes.

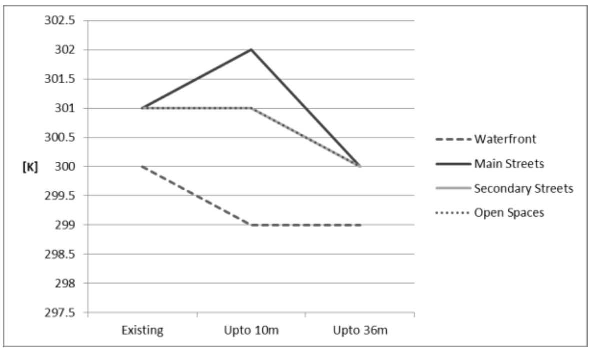


Figure 8: Comparison between the Surface Temperatures of the Three Designs in Terms of Human Comfort.
(Source: Authors)

Results from Figure 9 indicate that relative humidity was best in secondary streets and in open spaces between buildings in the 10 meters high design and were better in waterfronts and in the 36 meters design. Followed were the results recorded in the main streets of the 36 meters design. All results according to Table 3 were above comfort range according to indoor comfort codes.

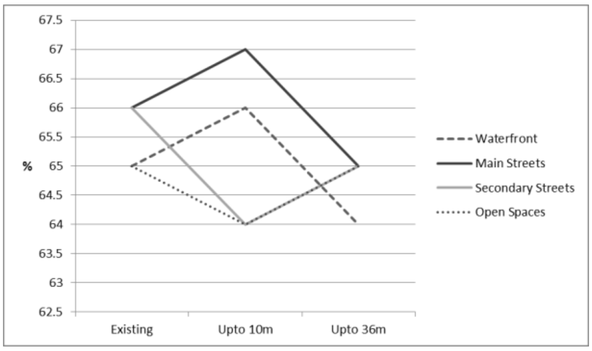


Figure 9: Comparison between the Relative Humidity of the Three Designs in Terms of Human Comfort. (Source: Authors)

According to Figure 10 wind speed was best in both current conditions and 10 meters high design. Current conditions were not a realistic solution since factories and storages though low rise had to be eventually moved. For the 10 meters design secondary streets were had the best readings. Followed were waterfronts, main streets and open spaces between buildings. Secondary streets had more impact than main streets and outdoor spaces. Least impact was on water front. All readings except for the 36 meters design as can be seen from Table 3 were within the comfort range.

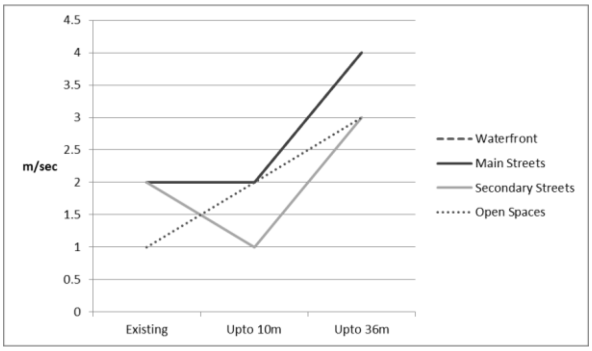


Figure 10: Comparison between the Wind Speeds of the Three Designs in Terms of Human Comfort. (Source: Authors)

GENERAL DISCUSSION

The study shows that improving microclimate by providing 10 meter high buildings at waterfronts, main streets, secondary streets and open spaces between buildings was the closest to comfort ranges compared to the 36 meters design. Readings of both surface temperature and wind speed were within comfort zones according to Egyptian indoor codes. Mean radiant temperature and relative humidity were higher than comfort ranges. Highest discomfort results were at main street readings, followed were at waterfronts then both secondary streets and open spaces between buildings. As a decision maker improvement must start at main street designs at the suggested proposal as well as choice of cool reflecting materials' choice, followed were more water bodies to be suggested and last but not least the vegetation. It is important to note that different designs might have different priorities but using simulation tools can help in making comparative quantitative readings and in turn make scientific decisions.

CONCLUSION

The purpose of this paper has been to present a general overview of the legislative conditions in a vital historic area and route in order to examine the close relationship between human comfort and urban design. To conclude the 10 meter design were more suitable for human comfort in comparison to the 36 meters design based on simulation test despite the suggested design. In addition, it was an attempt to review the possibility of changing the priorities through simulation tests on the different design parameters that had strong impact effect on microclimate. The contents have covered microclimatic enhancement methods that have strong impact on thermal comfort through simulation procedures.

This research has addressed a limited scope within the quest of viable strategies to achieve the broader environmental goals. This is a dynamic domain, one that continually engenders new ideas and involves new roles on the part of different stakeholders. It is believed that new theories and approaches will emerge as the physical environments and circumstances change. The role of planners and urban designers will thus acquire further significance in the field.

RECOMMENDATIONS

As a broad perspective, it could be concluded that the principle of urban design that affects microclimate and hence human comfort is a vital one, and needs to be considered/addressed through a number of recommendations, guidelines and special measures. The following is a focused set of recommendations based on the above-presented study:

- Set Egyptian Comfort Codes for outdoor spaces.
- Further studies could be conducted on other parameters such as shading elements or building orientation.
- Test different designs and different heights to reach a suitable legislative code.
- Combine studies with psychological studies in addition to physiological ones.
- Use albedo surface materials to reduce the mean radiant temperature.
- Choose simulation tools of reliable results prior to urban development.
- Human physiological comfort must merge with psychological needs which could be investigated by a simple questionnaire survey in future researches.

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