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A BIOCLIMATIC DESIGN APPROACH FOR THE URBAN OPEN SPACE DESIGN AT BUSINESS PARKS

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ABSTRACT

Urban open spaces have an essential role in business park design. This is because urban spaces not only affect the indoor thermal comfort of the surrounding buildings but also influence the outdoor activities of the users. This paper investigates urban open space design and its influence on outdoor thermal comfort. In this paper, a bioclimatic design tool is presented that has been developed for urban open space design in hot arid climates. This bioclimatic tool can provide guidance to the design of urban space attributes such as urban patterns, geometric parameters, paving materials, and vegetation percentage. The objective of this paper is to enhance the users' sense of outdoor thermal comfort. This will be achieved by applying the bioclimatic design tool that accounts for the effects of space parameters on the microclimate elements. The proposed bioclimatic design tool is evaluated based on two existing business parks in Egypt. The simulation results demonstrate the effectiveness of the proposed tool.

KEYWORDS: Business park, Urban open space, Geometric parameters, Paving materials, Outdoor thermal comfort.

1. INTRODUCTION

1.1 Overview on Business Parks' Urban Patterns

The economic and administrative centers in cities are classified into four types [1]: central business districts, technology parks, corporate cities, and business parks. A central business district is an urban environment that consists of the commercial and administrative center of a city, often referred to as the 'financial district'. Technology parks consist of offices and laboratories of companies that are involved in science and technology. Corporate cities are established by a specific industry to act as campuses for

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the industry, including head offices and exhibitions (e.g., the technical center of General Motors in Warren, Michigan).

Business parks are urban environment structures established in suburban areas. There are four types of business parks according to office buildings: 1)10% office buildings and 90% industrial services, 2) 40% office buildings and 60% industrial services, 3) 45% office buildings, 45% industrial services and 10% services, and 4) 80% office buildings and 20% services. The research scope in this paper is the fourth type [1]. As shown in Fig.1, business parks contain several office buildings, green landscaped areas, parking, and streetscaping.

Business parks started as a new design concept in 2000, when the office building first appeared in Egypt, and they are located away from the crowded capital [2]. The urban pattern of business parks can be central or linear as shown in Fig. 2. Figure 3 presents some examples of business park projects located in 6th of October city and New Cairo.

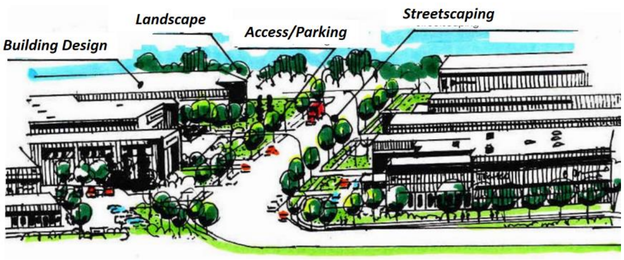

Fig. 1. Sketch for business park contents, [1].

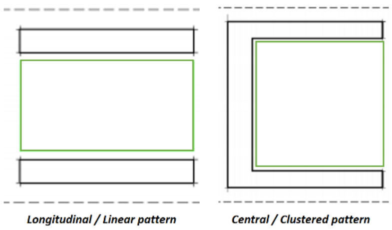

Fig. 2. Business park urban pattern.

1.2 Impacts of Urban Space Parameters on Microclimate

The urban environment structure features are the urban pattern, building distribution, open space shape, streets, vegetation, and paving materials. Open urban spaces have thermal and social functions. Urban spaces affect the indoor thermal comfort of the surrounding buildings, and also - influence the outdoor activities of the users. One of the elements used in measuring the quality of life in cities is the thermal balance of open spaces and the usability of these spaces in the outdoor activities of the users [3]. Urban spaces also have an impact on the amount of consumed energy. It was noticed that if the urban space is thermally balanced, energy can be saved up to 30% in commercial buildings, and 19% in residential buildings [3].

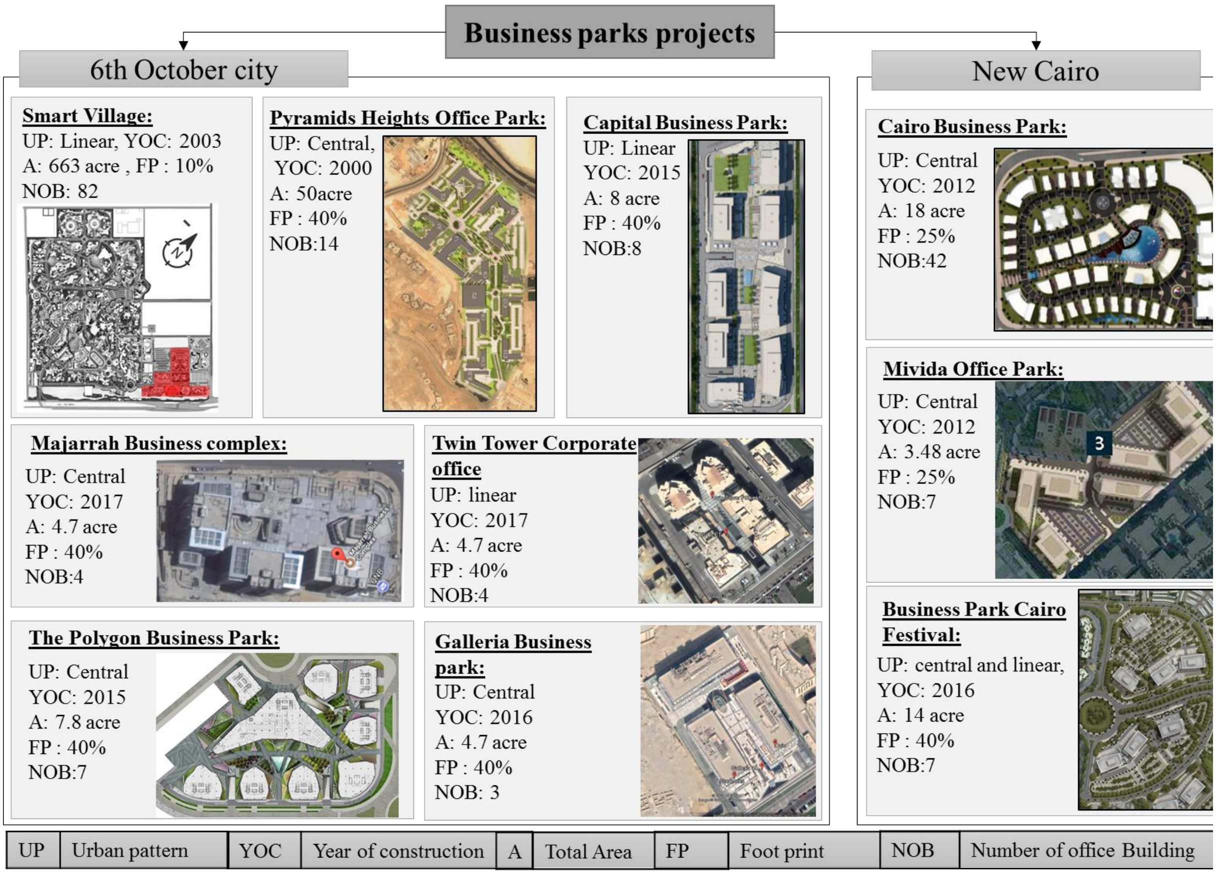

Fig. 3. Examples for business parks in Egypt.

The characteristic parameters of open urban spaces can be classified into three groups. The first group includes the geometric parameters such as orientation, aspect ratio H/W, and the sky view factor [4-6]. Both orientation and aspect ratio H/W affect incoming solar radiation to urban spaces, which in turn impacts the air temperature. Long-axis orientation of urban spaces controls the exposure of surrounding building facades to solar radiation and wind velocity in the spaces [4, 5]. The aspect ratio H/W of urban spaces impacts the formation of shading areas through the day and the amount of heat released to the sky at nighttime [6, 3].

Secondly, the thermal properties of finishing materials and surrounding buildings control the reflectivity, emissivity, and absorption of solar radiation to surrounding air [9-12]. Surface materials of surrounding building facades affect the reflected solar radiation. However, the reflected radiation is usually higher than the pedestrian level. Thus it has less impact on the space users [7]. The reflectivity and observation of paving materials directly affect the surrounding air temperature, where outdoor activities are practiced [8, 7].

Finally, the percentage of vegetation elements such as grass, shrubs, trees, and palm, as well as vertical green surfaces (green walls) comprise the third group of characteristic parameters of open urban spaces [9, 10]. The amount of vegetation controls solar radiation reflection and permeability. It also controls the wind direction and velocity. Table 1 summarizes some studies focusing on the impact of open urban parameters on micro climate.

Table 1. Impacts of open urban design parameters on the microclimate.

Parameter	Reference	Climate	Main findings
H/W ratio	[11]	Mediterranean	-The suitable H/W ratios for courtyard and square are 0.5, 1.0, and 2.0. -The effect of H/W ratio is inversely proportional to solar radiation exposure.
	[6, 3, 11, 12, 13, 14, 15, 16]	Hot arid	
Orientation	[6, 9, 7]	Hot arid	-North-South orientation is preferred with low H/W ratio. -East-West facades are exposed to the highest solar radiation.
Shading canopies	[8, 17, 16]	Hot arid	-Shading canopies decrease the daytime Ta, but sometimes they store heat underneath it at nighttime.
Paving materials properties	[11]	Mediterranean	-Natural soil is better than paving materials with low reflection index.
	[8, 18, 17, 19, 20]	Hot arid	-Paving materials with high solar radiation reflectivity increase Ta and MRT. -Asphalt has a high absorptivity and emissivity, which leads to a rise in Ta.
Vegetation cover	[9, 10, 13, 19]	Hot arid	-Increasing tree cover decreases the daytime Ta by 1.5o C and enhances the outdoor thermal comfort. -Grass cover has high absorptivity and low emissivity, which lead to the lowest surface temperature.

2. RESEARCH OBJECTIVES

In this paper, the design of urban spaces of business parks is investigated and its effect on the microclimate of the hot arid climate is determined. The paper's objective is to enhance the users' sense of outdoor thermal comfort, by applying the bioclimatic design tool that studies the effects of space parameters on the microclimate elements. These space parameters are the aspect ratio H/W, orientation, pavement materials, and vegetation percentage. Urban space microclimate can be measured through air temperature (Ta), wind speed (V), relative humidity (RH), and mean radiant temperature (MRT). The major contributions of this study are as follows:

1- The proposed bioclimatic design tool has been developed for urban open space design in the hot arid climate. This bioclimatic design tool considers the space parameters' effects on the microclimate elements. Designers can utilize this tool in the early design stage to facilitate the design of urban open spaces that achieve thermal comfort for space users. Applying this bioclimatic design tool does not require using environmental assessment software.

2- The proposed bioclimatic design tool is tested based on the evaluation of two existing business parks in Egypt. First, the thermal performance of the urban spaces of those business parks was simulated using ENVI-met V4. Then, new design scenarios were selected from the tool to improve the outdoor thermal comfort of those business parks.

3. RESEARCH METHODOLOGY

The research methodology presented in Fig. 4 illustrates the evaluation of the thermal performance of urban spaces to indicate the optimum urban space design parameters, by using the bioclimatic design tool. This bioclimatic design tool contains two prototypes for the urban space with various values for the parameters: H/W ratio, orientation, pavement materials, and vegetation percentage (ground cover). The ground cover was used in the study because we focused on the positive impact of grass cover on reducing the reflected solar radiation instead of pavement material. The resulting design scenarios were simulated using Envi-met version 4 for the summer season in the hot arid climate. The proposed bioclimatic design tool was tested based on two existing business park projects on the 6th of October city (30.05 °N, 31.24 °E), located in the western desert of Egypt.

4. SIMULATION TOOL

The simulations of the models were carried out with the three-dimensional model ENVI-met version 4.0. ENVI-met software provided capability, ease, and few data entries for building any urban environment [4]. ENVI-met is mainly used for simulating the impact of the urban space parameters on the microclimate and outdoor thermal comfort [9].

For the models' simulations, they were transformed in the model grid with the dimensions of 25×25×20 grids representing the real sites for the tested cases 50×50m at the horizontal level. The analysis simulation was carried out in the summer period on the hot-arid climate. The simulation took place during the working hours of the office buildings between 07.00 LST and 18.00 LST.

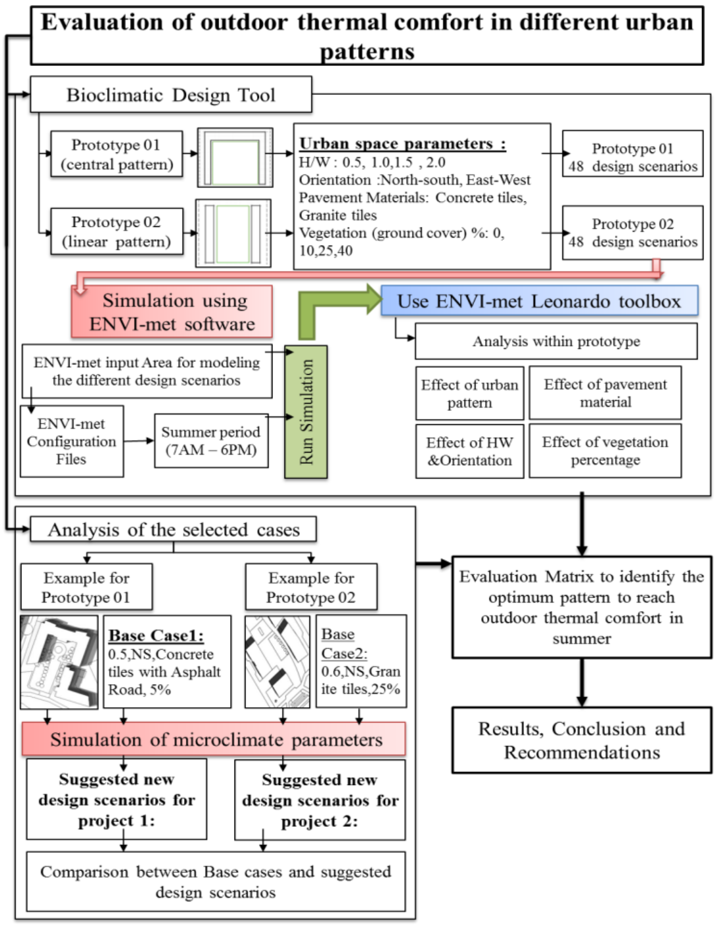

Fig. 4. Flowchart outlining the research methodology.

The climate of 6th of October city where the two projects are located, according to Köppen's climate classification, is a hot arid climate. This climate’s characteristics are high solar radiation intensities and average relative humidity of 43% annually. The weather data which was used at the simulation was based on 30 years of WMO Station no. 623660 records at Cairo International Airport. The hottest day, July 1, 2018, was chosen to represent the summer period. The climate data were converted into configuration files by using climate consultant weather data as shown in Table 2.

Table 2. Climate data input for simulations with ENVI-met for July 1, 2018.

Air Temp.	Relative humidity	Wind velocity	Wind direction	Cloud cover
31°C	38%	2 m/s	10 m/s	0/0/0 Oct.

5. PROCEDURES

First, the bioclimatic design tool flowchart was presented as shown in Fig. 5. In order to get this result, the tool guided the user to choose from a series of selections depending on each design scenario’s characteristics. All simulation results that were carried out by ENVI-met version 4 were saved in the core of the tool. The numerical values associated with the bioclimatic tool’s design parameters are listed in Table 3. Each scenario varied only by one parameter per time regarding H/W aspect ratio, orientation, vegetation percentage and the pavement materials in the two prototypes. For example, some design parameters were selected to form the design scenario “Case 5”, and the output were some microclimatic indexes that will appear with the selected scenario.

Second, a simulation for two existing urban spaces at business parks was conducted to evaluate its thermal performance. Then, the bioclimatic design tool was used to choose some new design scenarios which can improve these projects' thermal performance. The numerical values associated with the existing and new design parameters are listed in Table 4. Finally, a comparison was done between existing and new design simulation results as shown in Fig. 6.

Table 3. Bioclimatic tool's design parameters.

Total no of cases	96
Central space (H/W ratio)	0.5,1.0,1.5,2.0
Linear space (H/W ratio)	0.5,1.0,1.5,2.0
Pavement concrete surface Albedo	0.5
Pavement granite surface Albedo	0.8
Vegetation percentage (Grass) %	0,10,25,40
Orientation	North-South, East-West

Table 4. Case study's existing and new design parameters.

Design parameters	Existing design	New design scenarios	
Project 1 (H/W ratio)	0.4	1.4	2.0
Project 2 (H/W ratio)	0.6	1.0	2.0
Pavement Albedo Project 1	Asphalt	Concrete	Concrete
Pavement Albedo Project 2	Granite	Granite	Granite
Vegetation percentage Project 1	5%	25%	25%
Vegetation percentage Project 2	25%	25%	25%

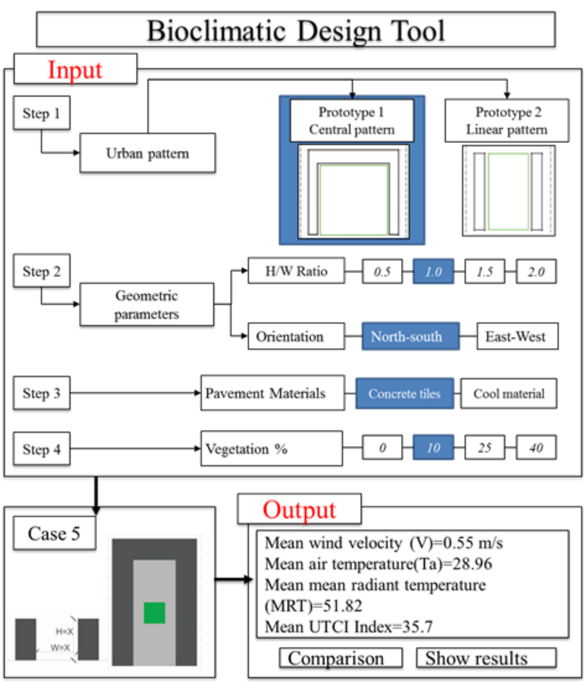

Fig. 5. Bioclimatic design tool flowchart.

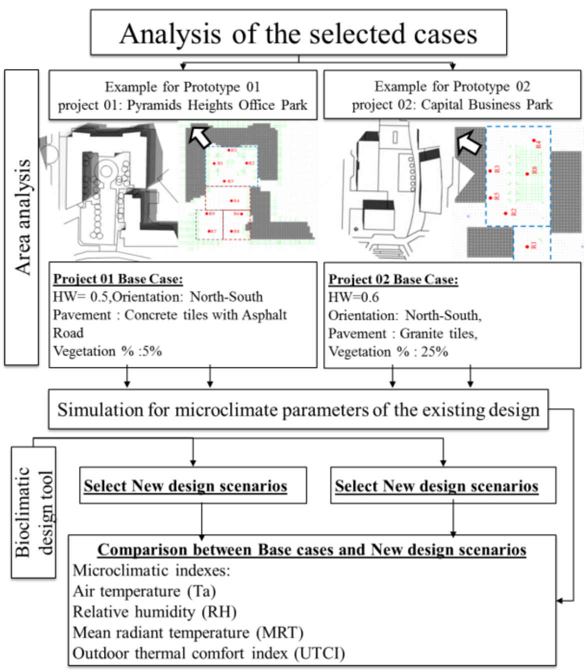

Fig. 6. Analysis of the tested cases flowchart.

The first project is Pyramids Heights Office Park, which represents an urban open space with a central pattern and traditional pavement materials (law reflectance and high absorption for solar radiation). The second project is Capital Business Park, which represents an urban open space with a linear pattern and high reflectance pavement materials. For each design scenario, outputs are the measured microclimate parameters which are air temperature (Ta), wind speed (V), relative humidity (RH), and mean radiant temperature (MRT). All measurements are taken at 1.8m inside the open urban space. The extracted results are used for the universal thermal climate index (UTCI) calculations available at http://www.utci.org/utci_doku.php.

6. RESULTS AND DISCUSSION

6.1 Bioclimatic Design Tool Simulation Results

The simulation studies and parametric analysis were aimed at a comparative evaluation of the effects different design parameters can have on microclimatic conditions and on the thermal comfort of pedestrians in outdoor urban spaces. This was carried out by assessing the effect of each parameter on two prototypes of open urban spaces, a central and linear pattern. For each prototype, hourly MRT and UTCI values were calculated. The results were examined separately for each design scenario. In addition, the area was averaged to provide an overall UTCI value representing each considered design parameter. The results are listed in Tables 5 and 6 according to their effects on the UTCI values.

Table 5. Influence of design parameters on MRT values for base case scenario compared to the suggested scenarios.

MRT(°C)			Central urban pattern				Linear urban pattern			
Orientation	Pavement material	vegetation%	H/W=0.5	H/W=1.0	H/W=1.5	H/W=2.0	H/W=0.5	H/W=1.0	H/W=1.5	H/W=2.0
North-South	Concrete	0	55.57	52.51	46.74	45.21	54.61	47.11	46.36	44.50
		10	54.87	46.70	46.27	45.86	53.63	46.98	45.14	43.86
		25	52.96	47.00	44.98	43.34	52.14	45.33	43.98	43.30
	Granite	0	54.26	48.14	46.42	44.66	52.65	47.59	46.47	44.80
		10	53.90	46.34	45.93	44.07	51.19	45.01	44.98	43.70
		25	51.22	45.88	37.25	41.60	50.57	45.88	44.01	43.02

Table 5. Influence of design parameters on MRT values for base case scenario compared to the suggested scenarios, (Cont.).

MRT(°C)			Central urban pattern				Linear urban pattern			
Orientation	Pavement material	vegetation%	H/W=0.5	H/W=1.0	H/W=1.5	H/W=2.0	H/W=0.5	H/W=1.0	H/W=1.5	H/W=2.0
East-West	Concrete	0	62.89	53.36	53.00	60.07	53.83	52.28	60.86	60.54
		10	58.87	53.11	51.93	59.95	45.50	51.25	50.54	60.19
		25	58.80	52.53	51.74	59.49	37.29	50.40	49.04	59.89
	Granite	0	59.23	60.19	52.65	60.16	58.73	60.44	60.44	60.22
		10	54.69	54.01	48.40	59.81	56.44	56.71	60.13	60.26
		25	51.72	52.14	34.46	59.27	55.91	52.14	51.47	59.74

Table 6. Influence of design parameters on UTCI values for base case scenario compared to the suggested scenarios.

UTCI (°C)			Central urban pattern				Linear urban pattern			
Orientation	Pavement material	Vegetation %	H/W=0.5	H/W=1.0	H/W=1.5	H/W=2.0	H/W=0.5	H/W=1.0	H/W=1.5	H/W=2.0
North-South	Concrete	0	34.4	36.6	32.4	32	37.70	34.90	35.20	34.90
		10	33.9	34.5	32.4	32.2	37.40	35.40	35.10	34.40
		25	32.7	34.6	32.1	31.8	36.40	34.90	34.80	34.00
	Granite	0	34.1	32.7	32.3	31.9	37	35.6	35.4	34.9
		10	34	32.3	32	31.8	36.5	34.8	34.8	34.5
		25	33.5	32.2	30.1	31.2	36.5	35.1	34.5	33.7
East-West	Concrete	0	36.1	34.4	35.4	37.7	33.9	34.2	36.9	39.9
		10	35.3	33.6	34.3	37.6	32.7	34.2	34.4	38.7
		25	33.2	33.2	33.6	37.5	31	33.2	33.8	37
	Granite	0	35.30	36.70	34.2	37.1	35.4	38.2	37.1	35.8
		10	34.70	34.5	33.1	36.3	35	35.6	37	36.4
		25	33.80	35	30.4	36.2	34.9	35.7	35.9	37.6

6.1.1 Effect of urban pattern

It can be noted from the simulation results that using a central pattern leads to lower Ta values. This is because the central urban pattern has more shading areas from surrounding buildings as shown in Fig. 7. Decreasing MRT values lead to an improvement in outdoor thermal comfort, as MRT is more effective on the UTCI index than the influence of Ta [21].

On average, the central pattern is observed to have lower values for Ta (by 1°C) and UTCI (by 2-3°C) than the linear pattern, as presented in Fig. 7. Moreover, higher wind velocity is observed in the linear pattern. This is due to the wind tunnel effect, in which air velocity increases with the increase of H/W values [19, 22].

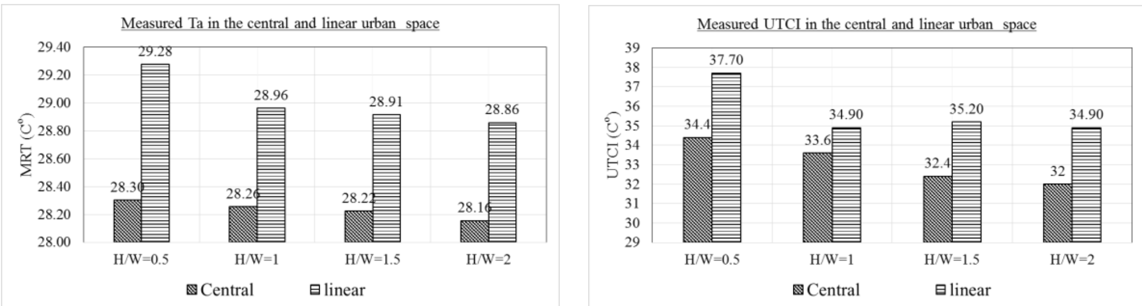

Fig. 7. Influence of urban pattern on Ta and UTCI index.

6.1.2 Effect of the geometric parameters

In the morning, the aspect ratio H/W is inversely proportional to the mean radiant temperature due to the shading effect [7]. At night, this relationship is reversed, as increasing H/W reduces the sky view factor that leads to a decrease in the rate of heat-releasing to the sky [12]. For both the central and linear urban patterns, doubling the aspect ratio (from H/W=0.5 to H/W=1.0) reduces the MRT values by 3.0°C and 3.5°C, respectively. These results conform to previous studies that were conducted in different climates [3, 23].

In summer, -in the hot-arid climate, it is recommended to orient the space axis along the North-South. This is because the North-South orientation provides maximum protection against direct solar radiation [14, 7]. As shown in Fig. 8, the East-West orientation, the simulation results show high MRT values in all aspect ratios.

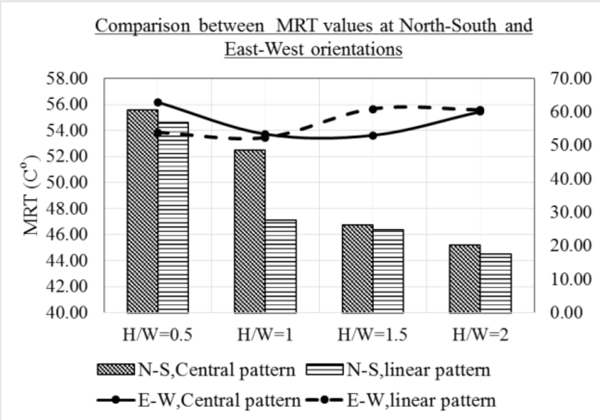

Fig. 8. Comparison between MRT values at North-South and East-West orientations.

6.1.3 Effect of pavement materials

Figure 9 illustrates the influence of pavement materials' albedo on the MRT values. The higher albedo values keep the surface of the ground cooler, while a high amount of solar radiation is reflected back to the surrounding surfaces. This reflected radiation raises the daytime MRT values [23, 13].

The simulation results show that an increase in the ground albedo from 0.5 to 0.8 raises the MRT value by 2◦C. The shading area, produced by high H/W, can reduce the amount of the reflected radiation. Therefore, it is recommended in the hot-arid climate over the high albedo materials.

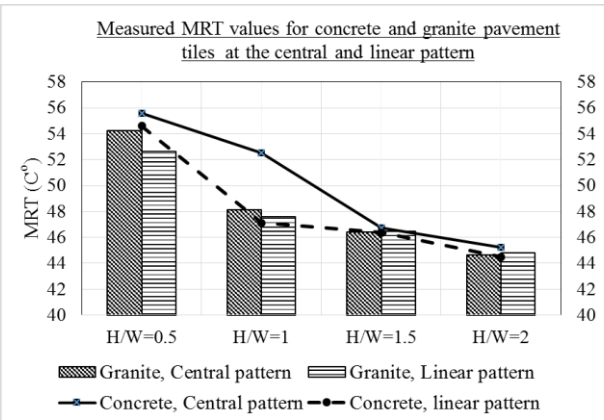

Fig. 9. Measured MRT values for concrete and granite pavement tiles at the central and linear pattern.

6.1.4 Effect of vegetation percentage

Using natural soil and grass cover, instead of paving materials with a high albedo value, have a significant influence improving thermal comfort [9]. This is because replacing pavement with grass cover decreases the reflected solar radiation and hence reduces air temperature. In Fig. 10 the simulation results show a reduction in the MRT value by 4°C at the central pattern and 5 °C at the linear pattern. Using vegetation percentage (25% and 40%) in the open urban spaces improves the MRT and UTCI values especially at H/W =1.5 in both patterns.

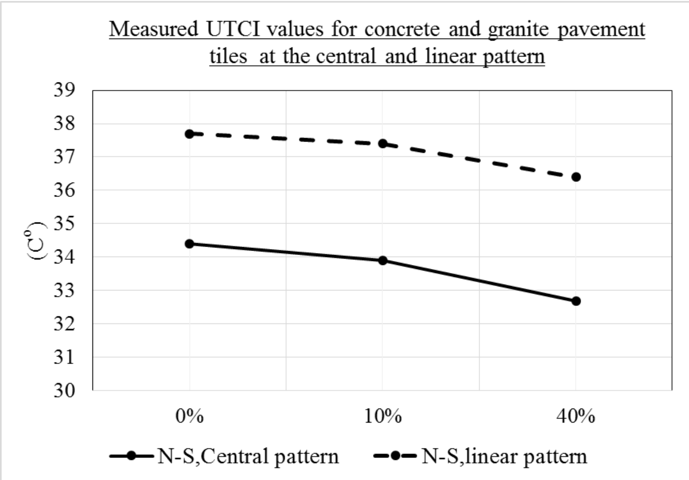

Fig. 10. Effect of vegetation percentage on the measured UTCI values.

6.2 Analysis of the Selected Cases

The comparison among the simulation scenarios is conducted through Leonardo toolbox. This toolbox allows a direct comparison between any two simulation results and indicates areas where the microclimate improved or declined. The measured Ta, MRT, and UTCI for project 1 and project 2 are shown in Figs.11-13 respectively.

In the first project, the peak values of Ta and MRT are recorded at (13.00 pm-16.00 pm). The existing design scenario, with H/W=0.4, Asphalt, and vegetation= 5%, has recorded the highest Ta and MRT values. This is because the low H/W ratio leads to the exposure of a high amount of solar radiation. Additionally, it uses Asphalt as a paving material that has high absorptivity and emissivity. In summer, the Asphalt's surface temperature reaches to 48-67°C, and this results in an increase in air temperature on the urban space [24]. The new design scenario 02, with H/W=2.0, concrete tiles, and vegetation=25%, has recorded a reduction of the average air temperature by 3◦C because of the high H/W ratio, and the introduction of shading areas at the open urban space.

In the second project, the peak temperature is recorded at (12.00 pm-15.00 pm). It is noticed that the existing design, with H/W=0.6, granite, and vegetation%=25, has recorded the highest air temperature among all other scenarios. This is because using high reflectance pavement material (granite=0.9) with a low H/W ratio introduces a high intensity of solar radiation at the urban space ground.

The results of the new design according to the methodology and as measured during the summer of 2018 indicate that the new design produces the following:

- A reduction of the average air temperature by (2-3°C) in project 01 and no remarkable change in project 02.
- A reduction of the average mean radiant temperature by (3-14°C) in project 01 and (2-10°C) in project 02.
- An improvement of the user thermal comfort by about 85.00% of the UTCI index

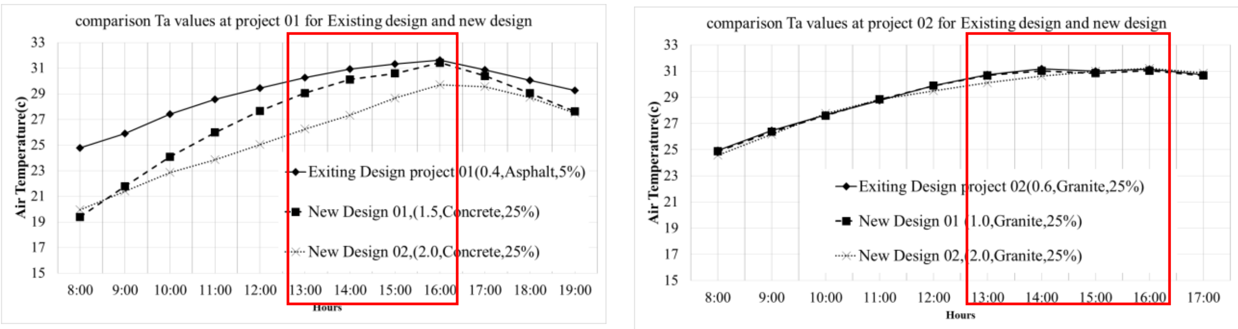

Fig. 11. Measured Ta at level 1.8m, left: Project 1, right: Project 2.

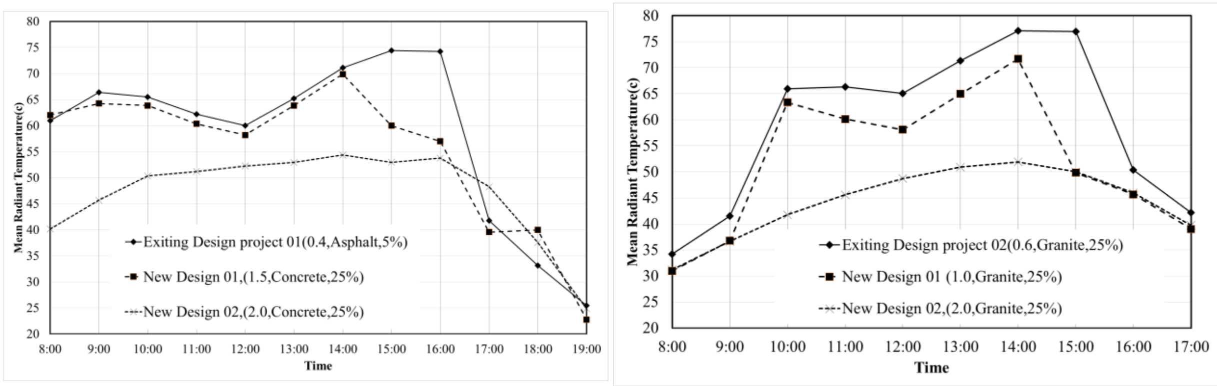

Fig. 12. Measured MRT at level 1.8m, left: Project 1, right: Project 2.

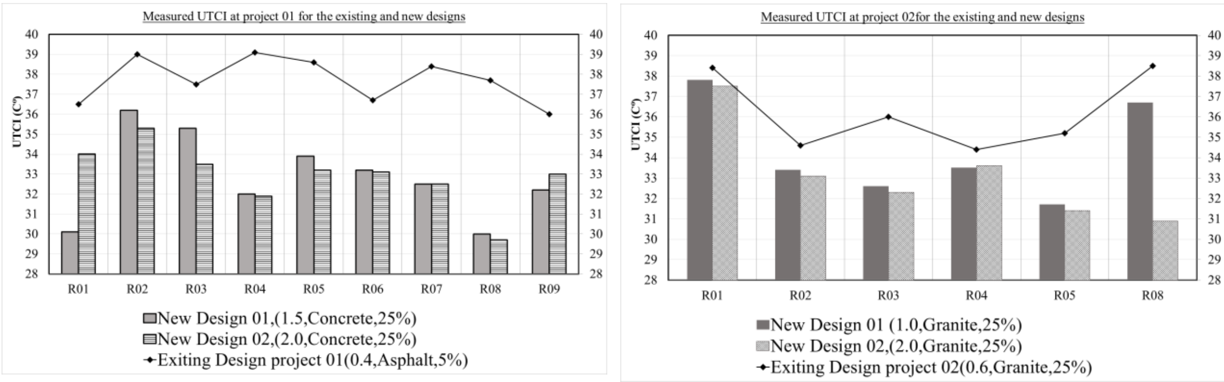

Fig. 13. Measured UTCI at level 1.8m, left: Project 1, right: Project 2.

7. CONCLUSIONS

Urban open space attributes, such as urban patterns, geometric parameters, pavement materials, and vegetation percentage affect the microclimate. The microclimate parameters influence outdoor thermal comfort and the usage of urban spaces. It has been observed that urban microclimate cannot be completely controlled, but can be enhanced by designing urban spaces with consideration of the effect of the climate elements.

- The proposed bioclimatic design tool has the following steps

1. The tool’s flowchart has been designed according to five group selections (urban pattern, aspect ratio H/W, orientation, pavement materials and vegetation percentage).
2. The simulations were carried out using Envi-met version 4 for the tool’s design scenarios.
3. The Leonardo toolbox was used for extracting the simulation outputs.

- The major results of this study can be concluded

1. The central urban pattern has more shading areas from surrounding buildings than the linear one.
2. The H/W ratio is a major factor affecting the thermal performance of the urban open space in a hot-arid climate. As the H/W ratio is high value, it can provide shading areas and decrease the solar radiation amount on the urban open space.
3. While the long axis of urban spaces is oriented to north-south, it decreases the surrounding buildings' facades exposure duration to the solar radiation.
4. Using pavement materials with high reflectance index can increase MRT and UTCI if this material is exposed to a large amount of solar radiation.
5. In the tested cases, it is shown that it depends on three parameters to enhance the outdoor thermal comfort. Those parameters are H/W ratio, pavement materials, and vegetation percentage.
6. The simulation results indicate that increasing the aspect ratio H/W from 0.5 to 1.5 while orienting the long axis to N-S improves outdoor thermal comfort by reducing UTCI values by 3^{o}C.
7. Grass cover and shading areas have a more significant effect on the microclimate of the central pattern than the linear pattern. However, this effect is notable only for more than 25% grass cover with aspect H/W ratio=0.5.

- Recommendations for architects, planners and urban designers

1. Central urban patterns provide more shading areas than linear ones. The linear urban pattern is the best at East-west orientation because it isn't trapped the solar radiation like the central pattern.
2. It is preferred aspect ratio H/W isn't less than 1.0 to provide shading areas to the space users and not more than 2.0 that may trap the reflected solar radiation in the open space.
3. Orienting open space to E-W direction in the hot arid climate exposed it to a big amount of solar radiation while increasing the H/W aspect ratio and vegetation percentage can decrease the reflected solar radiation at the open space.

4. High Albedo pavement materials are not suitable for hot arid climate without shading areas on top of the pavement.

DECLARATION OF CONFLICT OF INTERESTS

The authors have declared no conflict of interests.

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المدخل المناخي لتصميم الفراغات العمرانية المفتوحة في منتزهات الأعمال

يكون للفراغات العمرانية في المناطق الحضرية دور أساسي في تصميم مجمعات الأعمال. وذلك لأن هذه الفراغات العمرانية لا تؤثر فقط على الراحة الحرارية الداخلية للمباني المحيطة بل تؤثر أيضًا على الأنشطة الخارجية للمستخدمين. يركز هذا البحث في تصميم المناطق الحضرية المفتوحة وتأثيرها على الراحة الحرارية الخارجية. في هذا البحث ، نقوم بتطوير مدخل مناخي لتصميم الفراغات العمرانية المفتوحة في المناخ الجاف. يمكن للمدخل مناخي تقديم إرشادات لتصميم سمات الفراغات العمرانية مثل الأنماط الحضرية ، والصفات الهندسية ، ومواد الرصف ، ونسبة الغطاء النباتي. هدفنا هو تعزيز شعور المستخدمين بالراحة الحرارية في البيئة الخارجية ، من خلال تطبيق نهج التصميم البيومناخي الذي يأخذ في الاعتبار آثار عناصر تصميم الفراغ العمراني على عناصر المناخ المحلي. يتم تقييم مدخل مناخي المقترح من خلال التقييم لمشروعي منتزه أعمال قائمين في مصر ، وتظهر نتائج المحاكاة فعالية المنهج المقترح.