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URBAN GEOMETRY MITIGATION GUIDELINES TO IMPROVE OUTDOOR THERMAL PERFORMANCE IN EGYPTIAN HOT ARID NEW CITIES

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ABSTRACT

To keep up with world Rapid population growth in many countries including Egypt, the Egyptian government adopted polices to establish new urban communities, which many of them located in severe conditions of hot arid climate. However, the urban plans of those new cities do not prioritize the local climate considerations in its planning, which negatively effect on the thermal performance of urban spaces. In recent decades, greater attention was given to study the relationship between urban features and the local climate, developing mitigation and adaptation strategies with the aim of improving the thermal performance of urban spaces. So, this study aims to formulate a matrix of guidelines for urban heat islands mitigation strategies concerning urban geometry that can be helpful in improving the thermal performance of outdoor spaces in the existing new Egyptian cities -which allocated in hot arid climate zone, to enhance thermal comfort in these spaces.

To achieve this goal, a comprehensive review, and analysis of the impacts of different urban geometrical thermal mitigation strategies on outdoor spaces in hot-arid climate, is presented. The geometrical variables of urban spaces which have been investigated in the reviewed researches classified into two main groups (squares and plazas, canyons). The geometrical variables of squares and plazas include; side compactness, and Sky View Factor (SVF). Canyons geometrical variables are; SVF, aspect ratio and side profile shape. These variables depend on the features of those spaces which resulting from the urban pattern form and geometry. These guided values have been applied theoretically and practically on three real cases, to illustrate the mechanism of matrix guidelines applying on urban outdoor spaces thermal behavior initial evaluation and determine the most suitable environmental mitigation strategies directly. Applying of guidelines help in mitigating thermal behavior of plaza with about 18.73 k degree and the canyon space with 3.28 k degree. The discussion of this research clearly reflects the importance of urban planning guidelines that can be applied to help enhancing outdoor thermal comfort. This study is useful in controlling the climatic consequences of urban planning at an early stage.

Keywords: Outdoor thermal comfort, urban geometry, Hot-arid areas, urban heat island mitigation

1. Introduction

Recently, the world is witnessing a rapid increase in the population, in addition to the continuous population migration from rural to urban areas where it is expected that more than 70% of the world population will live in urban centers by 2050 [1] , causing the spread of urbanization, which is not sensitive to the current and future climate conditions. Furthermore, 85% of the population will be located in developing countries by 2030 According to the world development indicators [2], causing global warming.

Egypt alone is responsible for 0.6% of global emissions [3] According to Sarrat & Changnon [4][5], mortality rate is directly proportional to the impacts of global warming due to poor thermal comfort. for instance, the number of deaths in Melbourne exceeded 374 person because the four-day heat wave [6]. In addition to the cases in Europe, which range from 25,000 to 70,000 [7] [8]. Egypt is one of the countries that did not escape from the consequences of global warming [9]. However, a rapid reduction in greenhouse gases emissions (GHGs) could limit heat-related negative impacts in the future [10]. Harmful impacts are not only on human health but the global warming also increases the energy consumption [11][12][13], in addition to the high proportion of pollution[14][15].

As a result, the number of studies that have been concerned with improving the thermal comfort in urban spaces increased significantly [9]. Johansson [16] drew the attention to study the relationship between urbanization and climate change, reflecting its impacts on the thermal comfort [17]. Thermal comfort can be defined as the case in which you feel completely satisfied with the thermal environment [18]. Thermal comfort can be expressed by means of the physiologically equivalent temperature (PET), which is an up-to-date thermal index [19]. PET regarded to be an effective tool for thermal comfort evaluation in different climates [20]. It depends on human characteristics (age, gender, clothes, activity…) and natural elements (air temperature, sun radiation, relative humidity, wind speed…) [21]. Hence, it is possible to rely on urban planning strategies to improve the thermal performance of the urban environment by mitigating and adapting the influence of climate factors [22] [23] [24]. There are two main policy responses to climate change: mitigation and adaptation. Mitigation addresses the root causes, by improving the thermal performance of existing urban plans, while adaptation seeks to lower the risks posed by the consequences of climatic changes, which can be developed to prepare urban plans to suit local climatic conditions in the planning stage[25] [26]. Indeed, separating the variables of urban fabric strategies into categories is very difficult, since most of mitigation strategies can be used as an adaptation strategies if they applied prior to urban plans development [27]. However, in this study we have classified urban fabric variables base on which phase of urban plans they mostly used as shown in fig (1).

Egypt is one of the developing countries, which suffers from the rabidly growth population [12], where mean annual temperature is projected to rise by about 5.6°C on average from 1990 to 2100 [10], due to the number of days of warm spell is projected to increase on average from less than 10 days in 1990 to about 195 days in 2100. If emissions decrease rapidly, the days of warm spell are limited to about 45 on average [10]. The consequences of global warming negatively affect thermal comfort especially in the southern area, which suffers from severe climatic conditions [28][29][30]. The problem can be minimized by reducing the emissions rapidly, If that happened, the temperature rise will limited to about 1.6°C [10].

1.1. Problematic of the study

The Egyptian government is seeking to implement city plans for new urban communities to accommodate the large increase in the population [31]. As shown in fig

(2), most of those new cities are under implementation phase. Unfortunately, their urban and territorial plans are associated with lack of environmental considerations and the surrounding climatic conditions, which exacerbating the poor climate of those cities.

1.2. Aims

The research aims to make utilize of previous studies output by formulating a matrix of guidelines for urban geometry variables that can be helpful in mitigating the urban thermal performance of outdoor spaces in the existing new Egyptian cities plans, which allocated in hot arid climate zone and the spaces with similar climate conditions.

1.3. assumes of the study

The research assumes that by analyzing the previous experiments in improving the thermal performance of urban spaces in hot arid areas can be brought to direct strategies through its application directly on spaces with the same climate conditions, can improve their thermal performance.

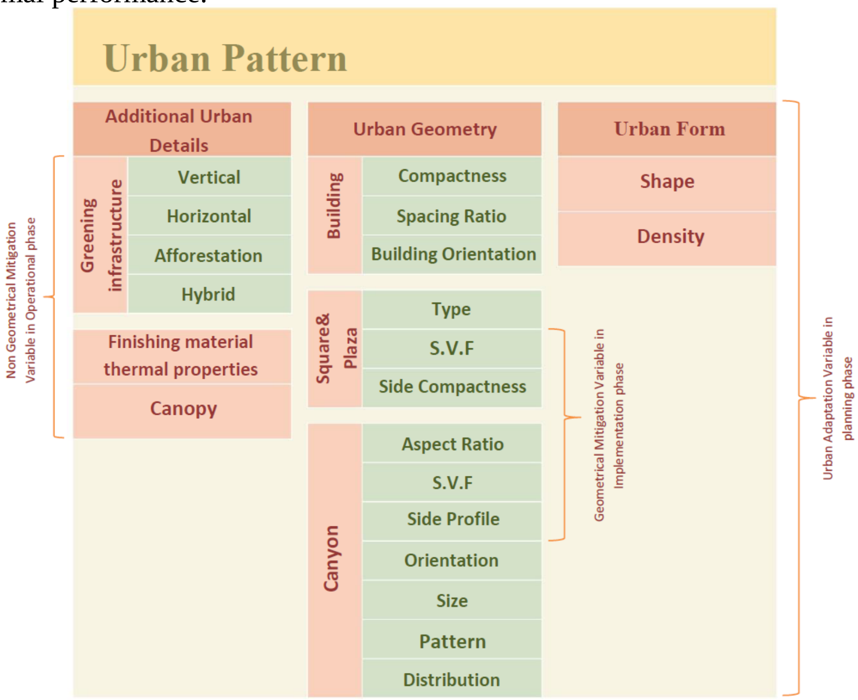


Fig. 1. classification of urban pattern variables to improve urban thermal performance in urban areas Source: [35] edited by author

Fig. 2. Implementation plans of new Egyptian cities Source: [113], [114] edited by author

2. Methods

The relationship between urban pattern and mitigation of urban heat island effects in hot dry climate is a rich material for scientific research. Due to the diversity of urban pattern mitigating variables affecting urban climate. Those variables can be divided into two main groups based on the phase of their case studies as mentioned before (geometrical, non-geometrical) variables. This research paper reviews a systematic range of literature on urban geometry thermal mitigation strategies and their effectiveness in affecting the thermal comfort on the pedestrian level under hot arid climate conditions. This review focuses on studies conducted on the bases of geometrical urban mitigation strategies in the implementation stage, where non-geometrical strategies were excluded. The goal of this research is to enhance the thermal behavior of outdoor spaces in the new Egyptian cities, through formulating user guides for the mitigation to reach this goal, the following steps were accomplished:

- A theoretical analysis of a set of researches based on climate measurements and simulations to rank climatic factors affecting the thermal comfort. to reach the suitable mitigation strategies, which can be followed in hot arid areas, and to enhance outdoor spaces thermal comfort
- A comprehensive literature analysis to determine the role of each geometrical variable on controlling the thermal behavior of urban open spaces allocated in hot arid areas.
- A matrix of guidelines represents the optimal mitigation strategies, which can be used to improve thermal comfort of outdoor spaces in hot arid areas.
- Applying guidelines on real case study

3. Ranking climatic factors influencing the thermal comfort in hot arid area

Climate is defined as the environment of the human being where the term "climate" includes all meteorological elements (air pressure, air temperature, humidity, clouds, precipitation, fog, etc.) and acquisition of heat exchange over a relatively long but limited period [32]. Nottingham et al. [33] [34] [35] also classified the meteorological elements into a set of variables (air temperature, relative humidity, wind velocity, solar radiation, surface temperature and etc.) as shown in table (1). The climatic parameter varies in their effects on thermal sensation according to each climate zone [3]. For instance, the intensity of solar radiation, which is one of the most important natural factors affecting the local climate, depends on latitude [36] [35]. The dry hot climate characterized by random and irregular rainfall that does not exceed 250 mm annually and some years it does not exist. Air temperature ranged from 20°c to 40°c [37] [38][39]. These conditions are considered very severe thermal conditions [40], humans cannot handle with and endanger their health [41]. Unlike the hot arid climate, tropical wet climate rains almost daily at an annual rate of approx. (60-100+ inches), an average temperature close to 26°c every month [3]. Consequently, urban geometry mitigation strategies varied from one climatic zone to another[42] [43]. Thermal comfort depends heavily on these climatic parameters [21].

It is therefore, significant to rank the effectiveness of different meteorological parameters influencing thermal comfort in hot arid climate zones to know the appropriate urban geometry mitigation strategies. Table (1) ranks a list of meteorological parameters that affect thermal comfort according to studies relied on climate measurements and simulations in hot arid areas. Air temperature has the largest share of the effects on microclimate in hot arid area in the listed researches, where Toudert [44] noted that air temperature, solar radiation and mean radiant temperature have more noticeable effect on the thermal comfort than air humidity and air flow which did not play a modifying role in his case study. Bou Khelkhal agreed with Toudert [45], where he focused on improving the thermal comfort of urban spaces by reducing their exposure to solar radiation, thus reduce the air temperature. Solar radiation (SR) and mean radiant temperature (Tmrt) were pointed out significantly in a substantial number of literature ([46], [47], [48]) as an effective factor affecting thermal comfort. Surface and Mean radiant temperature has been very much selected in the listed research as an effective climate factor affecting thermal comfort ([48], [49], [50]) where Johansson [48] in his study attributed the big difference between thermal comfort values, to the large differences in air temperature and mean radiant temperature degrees, in addition to the difference in the value of surface temperature, which reached 10 degrees in average.

From those significant findings, we must consider reducing the influence of these factors in urban areas with hot arid climate. Listed literature has shown the possibility of reducing the negative impacts of these factors on the thermal comfort in urban areas by increasing the percentage of shading to protect from direct exposure to solar radiation, depending on the strategies which will be reviewed in detail later. On the other hand, relative humidity was slightly indicated in the listed research, in terms of its effect on outdoor spaces thermal comfort in the hot arid areas, where hot arid climate characterizes by lack of rainfall. toudert [44] refers that even when plant elements added to a space located in the hot arid region, relative humidity still did not have a large influence . It worth mentioning recently that wind speed has a functional effect on thermal comfort according to Mayer, Pearl Mutter and Hassaan ([46], [51], [52]). Finally, there was no noticeable interest in listed research about Globe temperature (TG), Soil temperature and Global.

4. Effects of urban form geometrical variables on controlling the thermal behavior of urban open spaces allocated in hot arid areas

Urban form is determined by configurations of building blocks clustered with each other and interfaces (canyon, square and plaza) between them [53]. It was classified into two main groups that are dominantly used in public building complexes (regular -irregular). Those two groups were divided into four more detailed pattern (linear and aligned blocks) where canyons are straight and squares are regular and (Staggered and Zigzagging blocks) where the winding canyons and squares are irregular according to Fig. 3 [54] [55] [12]. Urban canyon was defined as “basic geometric unit which can be reasonably approximated by two-dimensional cross sections, neglecting street junctions, and assumes that buildings along the canyon axis are semi-infinite in length Oke 1988”. While the most simple definition of square and plaza can be the non-building land [56]. square and plaza were defined by [57] as the places which were left open or vacant in the spatial fabric of a city.

Table 1.

Climatic parameters affecting urban microclimate Source: The author

References	climatic factors influencing the thermal comfort											The impact of climatic factors on:			
	Air temperature (Ta)	Surface temperature (Ts)	Ground surface temperature	Soil temperature	Globe temperature (Tg)	Relative Humidity (RH)	Global radiant (Gr)	Solar radiation (SR)	Mean radiant temperature(Tmrt)	Wind speed (ws)	Wind direction (dd)	Thermal comfort	energy	microclimate	*Pollutant*
F. Ali-toudert and H. Mayer[44]	√							√	√			√			
E. J. Ã [48]	√	√							√	√		√			
F. A. Ã and H. Mayer [46]	√							√	√	√		√			
F. A. Ã and H. Mayer [49]	√	√	√	√					√					√	
I. Boukhelkhal and P. F. Bourbia [45]	√	√						√				√			
A. Shafaghat et all [35]		√										√			
L. Shashua-bar, D. Pearlmutter, and E. Erell										√		√			
F. Aljawabra and M. Nikolopoulou [47]	√					√		√		√		√			
A. Hassaan and A. Mahmoud [52]	√					√				√		√			
E. Johansson and R. Emmanuel [50]	√	√				√						√			

Urban geometry has a shared relationship with the local climate [43], where the style of urban pattern in many cities differs depending on the local climate [32]. For example, the combined pattern with narrow canyons is spread in hot climates, this pattern delivers higher shading by reducing the streets exposure to direct solar radiation [58] [59] [60]. While in cold areas, the spatial distances between the buildings are increased to allow solar radiation to penetrate as much as possible. Moreover, as an adverse reaction, we find that urban geometry of cities directly affects the local climate [61][62][63]. Urban geometry can improve the local climate or make it worse[64][65]. Its effect on outdoor spaces thermal comfort varies according to different values of these spaces’ geometrical variables. For example, the street orientation was observed as one of the most effective metrological characteristic on canyon thermal comfort [66] [67], as it has a great effect on the amount of solar radiation reaching the urban canyons, in addition to the speed and direction of the wind [68][69].

Aspect ratio, which defined as the ratio between the average height (H) of the canyon walls and the canyon width(W) according to [70], can affect the effectiveness of orientation variable on outdoor spaces thermal performance. Where canyon orientation is only effective in the canyons which have aspect ratio ranged from 1 to 4 [48]. According to aspect ratio values we can classify canyons into three main groups, 1) uniform canyon is considered if it has an aspect ratio of approximately equal to 1 (without major openings on the walls), 2) shallow if the canyon has an aspect ratio below 0.5, and 3) deep if the aspect ratio equals or higher than 2 [71]. Where orientation can be neglected for very deep and shallow canyons [49]. The two main orientation (North-South) and (East-West) are influenced by different proportions of surrounding climatic elements, this is due to the direction of the movement of the sun in N-S case is orthogonal on the axis of the canyon, In contrast to the (E-W) it is parallel to the canyon axis so solar access takes a shorter period in the first orientation than the E-W orientation [44]. For intermediate orientations(NE-SW) and (NW-SE), solar access take shorter time also than E-W but longer than N-S [72] [73], [46].

For a bigger scale, the fabric of urban pattern has a significant effect on outdoor thermal comfort [74][75]. Taleghani [76] studied comfortable hours in five different open spaces; East/West singular blocks, North/South singular blocks, East/West linear blocks, North/South linear blocks, and a courtyard block. He found out variable values according to the thermal behavior. Hence; the best condition was for the courtyard block with (17 hours of comfortable climate), while, the worst condition was for the singular blocks with its two orientations (just 2-3 hours of comfortable climate). Accordingly, the shape of urban spaces (squares and plazas or canyons) also affect the local climate where in hot humid and hot dry climates, the square or close to square courts is a good option as it can increase the percentage of the shaded area [77]. For polygons courtyards (pentagonal, hexagonal, heptagonal, and octagonal), the maximum amount of shaded area has been produced in the pentagonal courtyard through the day, but the heptagonal courtyard produces the minimum amount. However, in circular courts, it was completely shaded, where the solar radiation cannot reach the floor of the court, that due to the low solar latitude angle in winter [78].

Furthermore, the degree of building compactness also has a significant effect on the thermal behavior of outdoor spaces. Mohajeri, Gudmundsson, and Holloway [79] proved that a site with coverage of 10% is higher in annual solar radiation by 200 KWh/m2 than a site with coverage of 50%. The effects of urban geometrical variables have different values on affecting outdoor spaces thermal comfort, based on the type of these spaces. Therefore, these variables were classified into two main groups according to the type of the space as follows:

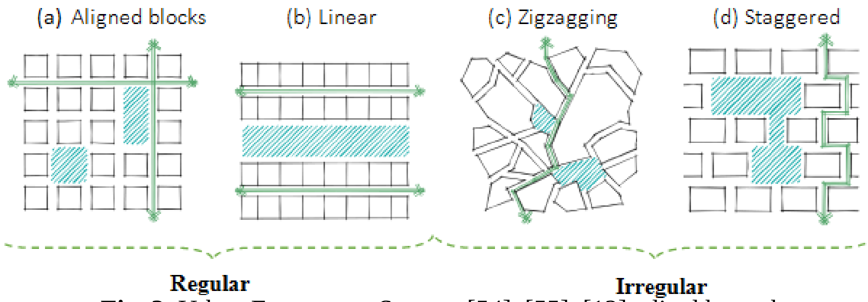


Fig. 3. Urban Form types Source: [54], [55], [12] edited by author

4.1. Geometry of squares and plazas

Squares and plazas have different types according to the urban form [80]. Zucker [81] classified all kinds of urban spaces into five main groups (closed, dominated, nuclear, Grouped and amorphous) [82][83] as indicated in fig (4). In hot arid areas, Nasrollahi, Hatami, and Taleghani [84] proved that the closed square is the most preferable in terms of daytime thermal sensation, as its shape produced the largest amount of shading comparing to the other shapes. The urban vacuum should be planned in a way that is appropriate to the surrounding atmosphere because of its thermal effect on the health, activity and progress of humans And therefore on the economic [56][85][47]. Table (2) represents a review summary of some researches that applied the strategies of enhancing squares and plazas thermal comfort in hot arid areas, by modifying urban geometrical variables. Urban geometrical variables affecting squares and plazas thermal comfort are limited to a pair of variables, sky view factor (SVF) and space side compactness. The SVF defined as " the extent of sky observed from a point as a proportion of the total possible sky hemisphere" [76]. Bourbia and Awbi mentioned [86][87] that buildings and vegetation surrounding outdoor space are the urban determinants which define the S.V.F value of these spaces[88].

Space side compactness, which represented in the closed ratio of the circumference of the vacuum [12], Based on that open spaces can be described as closed, Simi-closed or open space. Aspect ratio was neglected for squares and plazas, cause it has a very low value in them [72] [44]. On the other hand, SVF plays a significant role in influencing thermal performance of outdoor spaces [89], where we can modify the heat island effect by controlling SVF values [13] [90]. Its effect varies depending on the amount of shading produced, which differs for the same SVF according to its position inside the space and the orientation of the long axis of the space itself [91][92]. The values of SVF ranged from 0 to 1, where the value is a dimensionless number [90] . In hot-arid climate conditions, the value of SVF which equal 0.06 and 0.47 have a good effect on the open space thermal behavior as the solar radiation was not allowed to access the space for a long period during the day [93].

Another study in Melbourne found out that the Simi-covered space with SVF value near to 0 in hot arid area will increase the sense of thermal stress within the space [94].

The thermal importance of space side compactness is its control in the movement of air within the space In addition to the amount of shading [95]. The Simi closed space side is the most preferable in terms of thermal comfort at the daytime[40], while the closed space was the worst followed by the totally open spaces [40] [94], Which is different in being the best at night [95] as mentioned by in table (2).

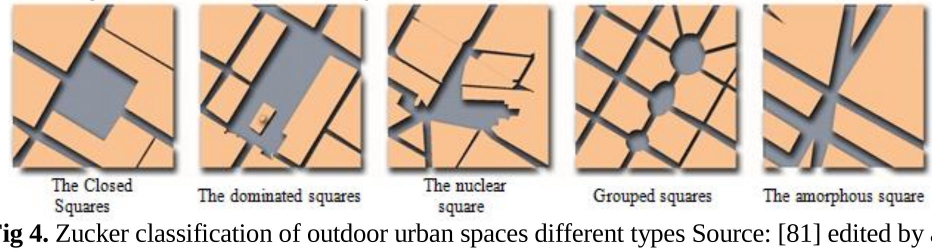


Fig 4. Zucker classification of outdoor urban spaces different types Source: [81] edited by author

4. 2. Canyon geometry

We Cannot call a space as canyon till its length is equal to six times its width [70]. Thermal behavior of canyons depends heavily on its urban configurations [96] [97].

Thermal performance in urban canyons varies, under the same climatic conditions, according to urban form and geometry of the urban pattern where these canyons located. In 1996, Golany [98] suggested narrow, winding, zigzagging alleys trying to achieve the maximum degree of shading by buildings and claims in desert cities in order to provide both solar protection during the day and remain warm during the night. While Shishegar [99] Found that wide straight and parallel configuration improved thermal sensation in urban canyons where the flow of air increased into and within a city. Unlike wide straight and parallel configuration, the narrow and winding streets block airflow. Therefor It is very important to improve the thermal performance of the streets because of their great impacts on the local climate and the consequent effects on human health [100].

Boukhelkhal [45] studied the effect of changing street side profile shape (facade, roof) as an urban geometrical variable, on its thermal comfort. Toudert and Mayer [44] were the first who proved that vertical profile can modify the thermal comfort significantly. Where five types of street section design (symmetrical, asymmetrical, overhanging facade, galleries and combined) applied as shown in the table (3). On different canyon orientation located in hot arid climate zone, the results showed that using Galleries is effective with (E-W) orientation, due to the fact that it is most exposed to thermal radiation [44]. However, for other orientation, it is preferred to use hybrid street design [44]. Galleries and overhanging streets can increase the average percentage of comfort time period with about 25% than the symmetrical streets [45]. Asymmetrical canyons make the situation worse in daytime thermal comfort [44] [49] [45], because of greater openness to the atmosphere than other designs. However, Asymmetrical canyons have proven to be effective in eliminating heat stress s at night [49].

Table 2.
Urban geometry heat mitigation strategies based on canyons b180behavior Source: The author

References	City& climate	Urban pattern variables						Square and plaza geometrical mitigation variables									The objective of the study improving:			Scenarios Results
		Urban form	Geometry																	
			kind of space					Side compactness			SVF									
											N-S			E-W						
		shape	Closed	dominated	nuclear	Grouped	amorphous	closed	Simi closed	Open	top	center	down	right	center	left	Thermal comfort	Air temperature	microclimate	
[93]	Hot arid, Rossio	(a)	-----	√	-----	-----	-----	√	-----	-----	0.94	0.93	0.06	0.42	-----	0.47	√			As this square loge axis parallel to N-S axis, the value of 0.06 and 0.47 have the greatest modification effect on thermal comfort
[101]	Hot dry summer, Mendoza city	(a)	√	-----	-----	-----	-----	√	-----	-----	From 0.82 to 0.21						√			The best SVF value was 0.82 which modified thermal comfort percentage with about 15% percentage
[95]	Hot arid, Emirates	(d)	-----	-----	-----	√	-----	√	√	√	neglected						√			PMV was pitter in Simi closed space with about 1.5 degrees rather than other spaces at daytime, however open space was little peter at night with about 0.5 degree
[102]	Hot arid, Isfahan, Iran	(b, c)	√	√	-----	-----	-----	√	-----	-----	neglected						√			The dominated shape is cooler than closed shape space with about 7% at winter time in terms of thermal comfort
[94]	Hot arid, Melbourne	----	√	-----	√	-----	√	√	√	√	0.027 for closed space & 0.472 Simi closed& 0.617 for open space shape						√		√	The highly shaded and closed site have the worst thermal behavior than the other scenarios
[45]	Hot arid, Ghardaia, Algeria	(b)	√	-----	-----	-----	-----	√			SVF= 0.88						√			Closed square with high open SVF leads to a higher thermal discomfort than the actual air temperature
[40]	Hot dry	(b)	-----	√	√	-----	√	√	√	√	neglected						√		√	Closed nuclear square has the worst thermal behavior and dominated Simi closed was better with about 5 Tg degrees

On the other hand, some studies tried to investigate the best roof profile shape in the term of canyon thermal behavior [103]. Hosseini [104] studied the impact of three different roof design shape with different aspect ratios, on velocity comfort, in hot arid areas as shown in fig (5). It was found that for shallow canyons with aspect ratio such as H/W = 0.5, increase in height and slope of the roof causes the thermal comfort of leeward, windward, as well central areas have moved away from the neutral comfort conditions. While short roofs (rise/run = 0 and rise/run = 3) is preferred in these canyons as the airflow velocity inside the canyon increased in the three positions leeward, windward, and central areas in non-isothermal condition [105]. The domed ceiling is not preferred in ordinary valleys with H/W = 1 where it decreases thermal comfort in leeward, windward, and central areas. In deep canyons where the aspect ratio is greater than or equal to 2, the level of thermal comfort rises within the valleys with flat roofs only.

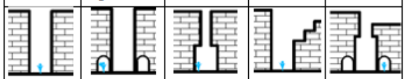
Fig. 5. different roof design shape Source: [104] edited by the author

In hot arid areas where the climate is characterized by the largest proportion of solar radiation [37] [38] [39], SVF has the greater effect on canyon thermal comfort. Yan, Vorontsov, and Dye [106] found that decreasing of SVF contributed to reducing the daytime air temperature of the canyon due to the blocking of a larger amount of solar radiation than open SVF. These results approved with the results of another study on Fez Morocco [48] where daytime air temperature decreases with SVF decreasing also [44]. However, reducing the SVF in a large amount is counterproductive in terms of thermal comfort at night [106] [49], due to the retention of heat in urban spaces and its inability to get rid of them by radiation to the surrounding atmosphere [107][108] [49].

One of the most effective geometrical variables was aspect ratio, where it has a significant effect on air temperature, which decreases with about 1K with each increase by a rate of 1 in aspect ratio value [73]. As if the canyon was very deep, its climate will be Isolated from the surrounding environment [48] [72]. Aspect ratio effect is reflected at night which mean that nighttime air temperature gets higher with higher aspect ratio [49][13][109]. From 2:4 h/w value regarded to be the most effective values as after them the impact of aspect ratio can’t make a significant effect on thermal comfort [72] [44]. Aspect ratio has nearly no effect when its value is less than 0.5 [46], [48]. For hot arid climate Golany and Grundström [98][110], proposed aspect ratio with values ($0.5 \leq H/W \leq 0.7$) for East-West oriented canyons and ($3 \leq H/W \leq 5$) for North-South canyons. Table (3) reviews a set of researchers' suggestions of aspect ratio values in hot arid climate to compare the results of geometrical thermal mitigation strategies produced by different aspect ratio values, in addition to side profile shape and S.V.F.

Table 3.

Urban planning heat mitigation strategies to improve urban plazas and squares thermal behavior Source: The author

References	City& climate	Urban pattern variables					canyons geometrical mitigation variables							study objective		Results
		Urban form	Geometry													
		shape	Canyon orientation				Aspect ratio (H/W)	S.V.F	Street side Profile Shape							
									A	B	C	D	E			
			(N-S)	(E-W)	(NE-SW)	(NW-SE)			symmetry	With galleries	Overhanging	asymmetry	hybrid	Thermal comfort	Urban microclimate	
																
[44]	Algerian Sahara-hot arid	----	√	√	√	√	2:1 for all orientation&1: 1 for main orientation	Wide & low	Used for main orientation	Used for all orientation	——	Used for all orientation	Used for all orientation	√		Galleries effective with (E-W) & intermediate orientation with low aspect and wide SVF , hybrid is good with all other orientation
[48]	Fez, Morocco hot dry	(c)	√	√	√	√	From0.6 to11 for main orientation& 0.6 to1.1 for intermediate	———	Neglected street design					√		Thermal comfort is more than 10 degrees comfort in deep canyon and orientation don't has a Significant effect in deep and shallow canyons
[46]	Ghardaia, Algeria -hot and dry climate	(c)	√	√	√	√	0.5,1,2,4 for main orientation& 2 for intermediate	———	Used for main orientation	——	——	——	——	√		for the same aspect ratio N-S is the lowest stressful and PET become better if it combined with aspect ratio equal or greater than 2
[49]	Constantine-Algeria semi-arid climate	(a)	√	—	√	√	From 1 to 6.7	From .076 to.58	——	——	——	Used for all orientation	——		√	Air& surface temperature increase with SVF increasing and H/W decreasing with about 6c. at the night open natural spaces is cooler than urban spaces with 3 or6 degree
[45]	Ghardaia-Algeria Hot Dry Climate	(b)	Neglected for deep and shallow canyon				.78, 2.22, 3.40, 3.75	From .176 to .88	Real case	Modification case	Modification case	Modificatio n case	——	√		the average percentage of time comfort for the PMV increases with more than 25% for modification scenarios
[73]	Ghardaia-Algeria Hot Dry Climate	(c)	√	√	√	√	0.5,1,2,4 for main orientation& 2 for intermediate		Used for all orientation	Used for all orientation	——	Used for all orientation	Used for all orientation	√		In hot arid climate Galleries effective with (E-W) (N-S) however hybrid style is the most effective in term of thermal comfort
[72]	Tunisia Mediterranean subtropical climate, a hot, dry summer season	(a, b, c)	√	√	√	√	From very narrow 4 and medium 1.84 to sallow 0.25 for all orientation	From 0.23 to 0.80	Used for all orientation	——	——	——	——	√		Thermal comfort in deep canyons with aspect ratio= 4 is pitter than the shallow canyons with 0.25 ratio by 8.48 ° C for the UTCI

5. Users guidelines

This study reviewed urban form geometrical variables as effective strategies influencing outdoor spaces thermal comfort in hot arid areas, with the aim of compiling the synthesis of experiments and recommendations presented in the literature related to improving the thermal performance of outdoor urban spaces in the hot arid area. Urban geometrical variables were presented as a guide in the form of a matrix reviews the effective values of urban form on improving thermal comfort in outdoor urban spaces located in the hot arid climate. The values were presented for each type of urban spaces (plazas and squares- canyons) based on urban pattern characteristics, which affect urban geometry variables on mitigating heat island effects, of these spaces. Urban pattern variables that affected geometrical urban mitigation variables, were divided into urban form and urban geometry variables.

The researches presented did not achieve the ideal values of thermal comfort in urban spaces, while they were able to improve it relatively; this is due to the severe climatic conditions of the dry hot climate. The results of the researches presented did not show a significant variation in the effective values of urban form variables that affecting outdoor spaces thermal comfort. Where recommended urban form variable values for each square and plaza type were almost identical in regular and irregular urban patterns. Researchers recommended the semi-closed side compactness for all squares and plazas. They also preferred the same values of SVF for squares and plazas, where the effective value in the middle of square or plaza ranged from 0.6 to 0.8, while it was preferred to reduce SVF values on the edges to reach 0.1 on the opposite sides of the sun.

On the other hand, the results showed a slight difference between effective urban form variables affecting canyons thermal comfort. As shown in table (4), for streets located in regular urban pattern and oriented to N-S axe it's preferred to use aspect ratio values ranged from 2 to 4, in addition to SVF values reduction until it reaches to 0.2. While preferable aspect ratio for E-W canyons ranged from 2 to 3 and SVF with the value from 0.3 to 0.5. In general hybrid side profile shape, found to be effective in terms of canyon thermal comfort enhancing for all canyons orientations expect E-W axe, where galleries is preferable. It is worth mentioning that flat roof is more effective in canyons with aspect ratio of more than 1, while for less aspect ratio values it is preferred to use an italic roof with the slope up to 3. Irregular urban patterns have slightly different values for canyon geometrical variables where aspect ratio values preferred to range from 0.7 to2 for all canyons orientations except N-S, which preferred to have an aspect ratio with values from 2 to 3. SVF was the same for all orientation, except the N-S orientation as mentioned in table (4). These guidelines are important because they inform the decision makers, planners and stakeholders of the effective values of different urban geometrical variables. These guidelines can be used in the early stages of the implementation of city plans in order to enhance thermal performance of outdoor urban spaces in hot dry climate.

Table 4.

Matrix guidelines of effective geometrical urban variables in mitigating outdoor spaces thermal performance Source: The author

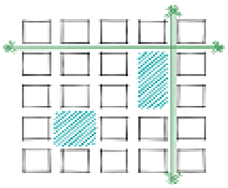
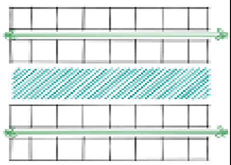
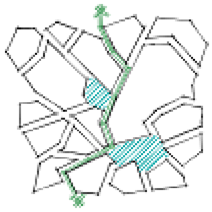
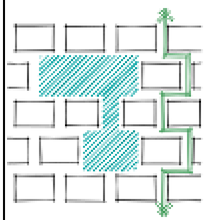
Urban pattern variables related to urban spaces				Suggested Geometrical urban values for canyons				Urban pattern variables	Suggested Geometrical urban values for squares and plazas	
Pattern type			Orient.	H/W ratio	SVF	Side profile		Kind of space	SVF	Side density
						roof	facade			
Regular	Aligned Blocks		N-S	2 to 4	0.2	Flat roof	hybrid	Closed	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed
			E-W	0.7 to 2	.3 to .5	Italic roof slope up to 3	galleries	dominated	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed
			NE-SW	2 to 3	0.3 to 0.5	Flat roof	hybrid	Grouped	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed
			NW-SE	0.7 to 2	0.3 to 0.5	Italic roof slope up to 3	hybrid	amorphous	From 0.6 to 0.8 in the middle for EW orientation and .5 for NS &.1 On the opposite edges of the radiation	semi closed
	Linear		N-S	2 to 4	0.2	Flat roof	hybrid	Closed	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed
			E-W	From .7 to 2	.3 to .5	Italic roof slope up to 3	galleries	dominated	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed
			NE-SW	From 2 to 3	.3 to .5	Flat roof	hybrid	Grouped	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed
			NW-SE	From .7 to 2	.3 to .5	Italic roof slope up to 3	hybrid	amorphous	From 0.6 to 0.8 in the middle for EW orientation and .5 for NS &.1 On the opposite edges of the radiation	semi closed

Table 4. (Cont.)

Irregular	Zigzagging		N-S	2 to 3	0.3 to 0.5	Flat roof	hybrid	nuclear	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed
			E-W	0.7 to 2	0.3 to 0.5	Italic roof slope up to 3	galleries			
			NE-SW	0.7 to 2	0.3 to 0.5	Italic roof slope up to 3	hybrid	Grouped	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed
			NW-SE	0.7 to 2	0.3 to 0.5	Italic roof slope up to 3	hybrid			
	Staggered		N-S	2 to 3	0.3 to 0.5	Flat roof	hybrid	Closed	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed
			E-W	0.7 to 2	0.3 to 0.5	Italic roof slope up to 3	galleries	dominated	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed
			NE-SW	0.7 to 2	0.3 to 0.5	Italic roof slope up to 3	hybrid	nuclear	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed
			NW-SE	0.7 to 2	0.3 to 0.5	Italic roof slope up to 3	hybrid	Grouped	From 0.6 to 0.8 in the middle &.1 On the opposite edges of the radiation	semi closed

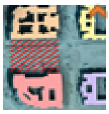
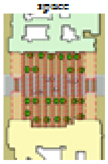
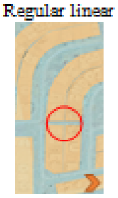
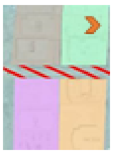
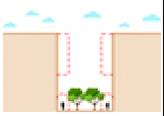
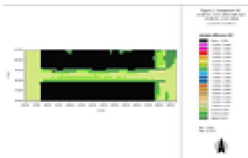
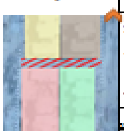
On, the other hand, the second case study was for a typical linear street at New Aswan with N-S orientation. The street's canyon had an aspect ratio of 1.5. Given that the range of values found in Table states that its H/W of these streets should vary from 2 to 4, but in this case it's not allowed to make the canyon narrower or to decrease the height of building so no change in aspect ratio can be applied. An intervention strategy based on changing canyon side profile shape and decrease SVF was proposed. The third case study however, was for another street with E-W orientation, H/W of 4.5 and S.V.F of 0.10. These characteristics perfectly coincide with what found in literature and therefore no sort of intervention is required on a geometrical level. If other micro-climate conditions improvements were required, then perhaps it should be achieved through green infra-structure or finishing material treatments. ENVI-met software used to simulate the modification of study cases thermal comfort. It is very often used to simulate urban built environments [111]. ENVI-met has been validated in many studies for its ability to simulate climatic factors conditions at the microclimate scale [112]. After applying the guidelines, which referred before, on the first case study, thermal comfort enhanced with a maximum value of 18.73 K degrees. While maximum thermal comfort optimization in canyon space was 3.28 K degrees.

6. Design guide application

As an example, to use the proposed design guidelines, three case studies with diverse special characteristics were selected in a new city in Upper Egypt (New Aswan city). These cases were evaluated according to the output of the study "the guideline matrix". The main goal of this is to demonstrate how the proposed criteria can provide a preliminary evaluation of thermal performance in these spaces as illustrated in table (5). The first case study was for an amorphous plaza with monumental scale at Aswan University’s new campus. The aspect ratio of that space was found to be (0.16) and S.V.F. of 0.85. These values do not coincide with what was found in literature and hence an intervention is required. According to Table (5) when the aspect ratio is less than 0.5, its impact can be neglected. Consequently, proposing H/W relevant strategies will not be feasible. Instead, a strategy based on installing shades to reduce the S.V.F to become within the range of 0.5 to 0.1 will be the preferable strategy.

Table 5.

An example of guidelines using to make initial evaluation of outdoor spaces thermal performance Source: The author

Spaces current situation						Space initial evaluation	initial Recommended mitigation strategies			
Urban pattern type			Space type	Geometrical characteristics			Sketch for initial Strategies	geometrical recommendation		Initial thermal modification results
Urban planning phase	Under construction plan	Regular aligned block 	Amorphous square 	S.V.F	0.85	Inappropriate	Reducing SVF and make the space Simi closed space 	S.V.F	0.5	
				Side dens	Open			Side dens	Simi closed	
	Under construction plan	Regular linear 	N-S oriented canyon 	S.V.F	0.3	Inappropriate	Reducing SVF and change side profile shape as allowed 	S.V.F	.18	
				Aspect ratio	1.5 fixed			Aspect ratio	Change not allowed	
				Side profile shape	symmetry			Side profile shape	hybrid	
	Under construction plan	Irregular staggered 	E-W oriented canyon 	S.V.F	0.10	appropriate	No geometrical strategies recommended allowed			
				Aspect ratio	4.5					
				Side profile shape	symmetry					

On, the other hand, the second case study was for a typical linear street at New Aswan with N-S orientation. The street's canyon had an aspect ratio of 1.5. Given that the range of values found in Table states that its H/W of these streets should vary from 2 to 4, but in this case it's not allowed to make the canyon narrower or to decrease the height of building so no change in aspect ratio can be applied. An intervention strategy based on changing canyon side profile shape and decrease SVF was proposed. The third case study however, was for another street with E-W orientation, H/W of 4.5 and S.V.F of 0.10. These characteristics perfectly coincide with what found in literature and therefore no sort of intervention is required on a geometrical level. If other micro-climate conditions improvements were required, then perhaps it should be achieved through green infra-structure or finishing material treatments. ENVI-met software used to simulate the modification of study cases thermal comfort. It is very often used to simulate urban built environments [111]. ENVI-met has been validated in many studies for its ability to simulate climatic factors conditions at the microclimate scale [112]. After applying the guidelines, which referred before, on the first case study, thermal comfort enhanced with a maximum value of 18.73 K degrees. While maximum thermal comfort optimization in canyon space was 3.28 K degrees.

7. Conclusion and recommendation

Due to the rapidly growing population density in Egypt, it is necessary to provide new cities covering current and future housing needs. The main objective of these cities was to provide housing, but their plans did not fully consider the surrounding climatic conditions, that would have negative effects on pedestrian thermal comfort, and the consequences of serious public health issues. Urban planners should be concerned with linking urban planning policies with local climate conditions that affect people's thermal well-being and therefore their health. Therefore, a wide range of published research papers were reviewed, their findings and recommendations summarized, to inform urban planners and stakeholders about the effective values of urban geometrical variables, which enhancing outdoor spaces thermal comfort in hot arid areas.

The first part of this study ranked climatic factors affecting the thermal comfort, to reach the suitable mitigation strategies in hot arid areas. Increasing shading ratio with urban geometrical variables one of the most suitable geometrical heat mitigation strategies in hot arid climate, where solar radiation and air temperature found to be the most effective climatic factors affecting pedestrian thermal comfort in outdoor spaces.

The second part conducted a comprehensive literature analysis to determine the role of each geometrical variable on controlling the thermal behavior of urban open spaces allocated in hot arid areas. Geometrical variables were classified into two groups according to the kind of outdoor space (canyon, square and plaza). These variables were summarized in (SVF, aspect ratio, side profile) for canyons and (SVF, side density) for urban spaces. Urban planners should be concerned with linking urban planning with local climate conditions that affect people's thermal well-being and therefore their health.

The submitted matrix represents the optimal mitigation strategies, which can be used to mitigate the heat stress in hot arid areas by manipulating the urban geometry. It is a useful tool for urban planners as preliminary evaluation existing and proposed plans, and guidance for optimal strategies cope with more climate sensitive urban environment.

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نحو مواءمة للشكل الحضري لتحسين الأداء الحراري للفراغات الحضرية الخارجية في المدن المصرية الصحراوية الجديد

الملخص العربي

لمواكبة ظاهرة النمو السكاني المتسارع عالميا في أغلب الدول ومنها مصر, قامت الحكومة المصرية بتبني فكرة إنشاء مجتمعات حضرية جديدة خارج وادي النيل الضيق, والتي وقع اغلبها في نطاق المناخ الحار الجاف. لكن المخططات الحضرية للمدن الجديدة لم تكن إعتبارات المناخ المحلي من اولوياتها, والذي أثر سلبا علي الأداء الحراري للفراغات الحضرية بهذه المدنز

في العقود الاخيرة حدث إهتمام بحثي كبير بدراسة العلاقة بين الخصائص الحضرية والمناخ المحلي, وذلك لتطوير استراتيجيات للتكيف والتلاؤم مع المناخ المحلي بغرض لتحسين الأداء الحراري للفراغات الحضرية. لذلك فإن هذه الدراسة تهدف لتقديم مصفوفة لخطوط إرشادية لإستراتيجيات التلاؤم البيئي المرتبطة بالشكل الحضري والتي تساعد علي تحسين الأداء الحراري للفراغات الخارجية بالمدن المصرية الجديدة فى المناخ الحار الجاف. ولتحقيق هدف الدراسة تم عمل مراجعة نظرية شاملة وتحليل للقيم الهندسية لاشكال الفراغات الحضرية المختلفة وتاثيرها علي الأداء الحراري للفراغات الحضرية.

المتغيرات الشكلية للفراغات الحضرية التي إستعرضت في الابحاث السابقة تم تصنيفا الي مجموعتين رئيسيتين (متغيرات خاصة بالساحات والميادين, متغيرات خاصة بالممرات). المغيرات الشكلية للساحات والميادين كانت (معامل رؤية السماء و كثافة المباني علي حواف الفراغ). بينما كانت تلك المتغيرات (هي نسبه العرض للإرتفاع, معامل رؤية السماء وشكل القطاع الجانبي) بالنسبة للممرات. تعتمد قيم هذه المتغيرات على السمات الشكلية للفراغات الحضرية الناشئة من شكل وهندسة النسيج الحضري.

تم تطبيق القيم الإرشادية المستخلصة نظريا وعمليا علي ثلاث حالات واقعية بغرض توضيح آلية تطبيق المصفوفة الارشادية في عمل تقييم مبدأي للأداء الحراري للفراغات الحضرية الخارجية من اجل الوصول لأنسب تقنيات الموائمة البيئيه بصورة مباشرة ، ساعد تطبيق القيم المستخلصة في المصفوفة على تحسين الراحة الحرارية داخل الحالة الدراسية بقيمة 18,73 درجة كلفن كحد أقصي للتحسين, بينما وصل اقصي تحسين في الممرات الي 3,28 درجة كلفن.

تعكس مناقشة البحث بصورة واضحة اهمية الإرشادات التخطيطية الحضرية التي يمكن تطبيقها لتحسين الراحة الحرارية الخارجية.