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Energy Efficiency Design Guide for Optimal Urban Features of Open Spaces in Residential Complexes

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Abstract

The energy consumption in buildings and especially residential buildings is immensely affected by the design of urban open spaces around these buildings. Many countries including Egypt have been witnessing rapid growth in residential complexes while the effect of urban design on microclimate and energy use is not given appropriate considerations. Accordingly, this has contributed to the massive increase of energy consumption. Many studies have been conducted for analyzing the effects of urban features of open spaces (variables) and their values on the microclimate. A set of values for one or more variables were addressed in each of these studies and their effect on urban microclimate and energy use were measured. However, such effects were diverse and dispersed.

Therefore, the aim of this paper is to identify the optimal settings of urban features of open spaces that contribute to reducing energy consumption in buildings and achieve outdoor thermal comfort in the context of urban open spaces in residential complexes. In order to achieve this goal an extensive and thorough literature review is conducted for classifying and analyzing the impacts of different values of each urban feature of open spaces on energy use and thermal comfort. The urban features of open spaces in residential complexes are classified into five categories: urban morphology, street pattern, urban density, building distribution, and urban canyon. There are various sub-variables for each category with corresponding range of values which are classified into different sets. Each set corresponds to the same urban pattern and climate zone. The results of these sets and categories are comparatively analyzed in order to identify the optimal values that contribute to reducing energy consumption in buildings and achieve outdoor thermal comfort.

The outcome of this extensive comparative analysis is resulted in the form of five main urban patterns (that are dominantly used in residential complexes), for the two climate zones in Egypt (hot arid, and hot humid) along with the optimal urban design features of these five main urban patterns. The outcome of this research paper is presented in a matrix format that graphically presents these urban patterns and the optimal values of the urban open space features (variables) along with the indicators of energy consumption and outdoor thermal comfort. This matrix provides architects and building designers with a useful and friendly design guide that can be used at the early phases of urban design and can help them to achieve energy efficient and comfortable urban-open spaces in residential complexes. Such design guide will contribute in improving the awareness of designers at the early phases of the design process and direct their designs to be energy conscious and efficient prior to the detailed design phase wherein energy simulation is time-consuming and expensive.

Keywords

Energy Efficiency; Urban Design; Features Urban Open Spaces; Residential Complexes; Outdoor Thermal Comfort

1. Related Work and Motivation.

Urban open spaces in residential complexes have different design characteristics and features that have immense impacts on its local micro-climate (Bourbia and Boucheriba, 2010; Yahia and Johansson, 2013). One of these negative impacts is that micro-climates have higher air temperature than their surroundings. This phenomenon is called Urban Heat Island (UHI) (Taleghani, 2016). The UHI mainly occurs because of using man-made materials, structures, and surfaces instead of natural materials and elements (Yahia and Johansson, 2013). These men-made elements and materials trap large amount of solar radiation during the day and release it at night (Doherty et al, 2009). The UHI increases the need of air conditioning in the buildings in order to ensure occupants' thermal comfort which in turn increases energy consumption. On the other hand, UHI negatively affects the outdoor thermal comfort (Krüger et al, 2011).

Urban design plays a crucial role in determining energy efficiency of buildings and environmental friendliness of outdoor spaces. Accordingly climate is expected to be one of the urban design criteria (Abed, 2012; Martins et al, 2012). Nowadays, urban complexes are the main energy consumer. Indicators worldwide reveal that improving urban communities will free up large amount of current energy demand (Bayoumi, 2012; Krüger et al, 2011).

Many urban design features influence climate at local-scale such as urban morphology, urban structure, buildings distribution, orientation, urban density, and many other factors. There is a strong relationship between these features and energy consumption in buildings and thermal comfort of outdoor spaces (Doherty et al, 2009; El Dallal and Visser, 2015). Previous studies examined different sets of these features and their relationships. For instance; orientation, aspect ratio, height of trees, planting distance of tree, and tree's leaf area index (LAI) for a street were examined to demonstrate their effects on microclimate and energy consumption in a hot humid climate (Huang and Li, 2017). Another study examined the relationships between orientation, aspect ratio, and spacing between buildings and their effects on energy cooling load. The study concluded that; in order to decrease cooling demands for buildings, urban design has to provide a large aspect ratio, small spacing ratio between buildings, and street oriented to North-South axis (Abed, 2014). However , a thorough analysis of these urban features of open spaces and their relationships is required to clearly articulate their impacts on energy consumption and outdoor thermal comfort

2. Research Problem and Objectives

Several past studies have been conducted for determining the impacts of urban open space features (variables) and their values on the microclimate and the heat mitigation strategies of UHI at the neighborhood scale (Taleghani, 2016). These studies investigated the effect of urban design on energy demand of buildings (heating and cooling demands), climatic parameters (air temperature, relative humidity, wind speed, and solar radiation), and outdoor thermal comfort for occupants and pedestrians in open spaces (Okeil, 2010; Yahia and Johansson, 2013). Developing countries have been witnessing rapid growth in residential complexes, while the effect of urban design on microclimate and energy use is not given appropriate considerations (Martins et al, 2012). These urban features of open spaces are diverse and their relationships are dispersed. Accordingly, this paper is attempting to overcome this gap and aims to comprehensively analyze the impacts of urban features of open spaces in residential complexes in both the hot arid and hot humid climates in order to identify the optimal urban features that contribute to achieving energy efficiency and outdoor thermal comfort.

3. Research Methodology

In order to achieve the aim of this study, the following procedures were conducted:

– Conducting a thorough analysis of literature to categorize the impacts of each of the urban features of open spaces (urban pattern, urban canyon, building distribution, and shape of the open space) on both energy consumption and outdoor thermal comfort.

– Addressing the impacts of vegetation and finishing materials on both energy consumption and outdoor thermal comfort.

– Comparing the different values for each of the urban features of open spaces and developing a set of classifications based on their impacts on both energy consumption and outdoor thermal comfort and accordingly identify the optimal urban features.

– Developing a matrix that represents the optimal features of open spaces along with their associated impacts on both energy consumption and outdoor thermal comfort that can be used as a guide.

3.1. Analyzing the Impacts of Urban Features of Open Spaces on Energy Consumption and Outdoor Thermal Comfort

This paper conducted a thorough analysis of the literature that resulted in categorizing the impacts of each of the main urban features of open spaces (urban pattern, urban canyon, building distribution, and shape of the open space) on both energy consumption and outdoor thermal comfort as articulated in the following sub-sections. Also, the impacts of vegetation and finishing materials are addressed.

3.1.1. Urban Pattern

Shape
Taleghani, et al (2014) studied comfortable hours in the open space for different shapes of urban patterns; East/West singular blocks, North/South singular blocks, East/West linear blocks, North/South linear blocks, and a courtyard block. The worst condition was for the singular blocks with its two orientations (just 2-3 hours of comfortable climate), and the best condition was for the courtyard block (17 hours of comfortable climate). Also other studies demonstrated that linear fabric and courts patterns have potentials to save more energy for cooling demand, as they receive less solar radiation for roofs, facades, and ground than singular blocks (Okeil, 2010; El Deeb et al, 2012; Sanaieian, 2013; Nguyen Van et al, 2014; and Allegrini, 2015). Also air flow between buildings is determined by the orientation of the urban pattern. The urban pattern has to be oriented parallel to prevailing wind direction (Busato, 2003; Prayitno, 2013; Bayoumi, 2013; Padilla-Marcos et al, 2016).
Density
The increase of density (number of dwelling units(du) per floor area) increases the total loads of energy. A case of 9 du/1000 m2 of density recorded less heat gain in summer and less heat loss in winter than a case of 14 du/1000 m2 of density (Asfour and Alshawaf, 2015). The increase of site coverage (percentage) resulted in decreasing annual solar irradiation. A site with coverage of 50% is less in annual solar radiation by 200 KWh/m2 than a site with coverage of 10% (Mohajeri et al, 2016).

3.1.2. Shape of Open Space

Shape
In hot humid and hot dry climates, the square or close to square courts can increase the percentage of shaded area and decrease the cooling energy demand (Yasa and Vildan, 2014). The increase of form elongation (approaching

court to a square shape) causes an increase of cooling energy loads. For polygons courtyards (pentagonal, hexagonal, heptagonal, and octagonal), the pentagonal courtyard produces the maximum amount of shaded area through the day while the heptagonal courtyard produces the minimum. However in circular courts, the solar radiation cannot reach the court floor, which means that it is completely shaded due to the low solar latitude angle in winter (Muhaisen and Gadi, 2005).
Proportions
The increase of the height of surrounding buildings can decrease cooling demand, despite increasing the use of energy for lighting (El-Deeb et al, 2014). In a temperate climate, buildings with an inner court can consume less energy for cooling demand if floor perimeters/building heights =1 (which indicates the depth of a court) and length/width of a court = 0.1 (which indicates the elongation of a court shape) (Muhaisen and Gadi, 2006).

3.1.3. Urban Canyon

Aspect Ratio
In a hot dry climate, the increase of Height/Width (H/W) ratio can decrease air temperature (Ta) moderately. Moreover wide streets (H/W<1) are thermally uncomfortable for occupants and pedestrians (Toudert and Mayer, 2007). For a hot-humid climate the courtyard with the value of Aspect Ratio =1 is 1 degree cooler than the courtyard with Aspect Ratio = 0.167 (Ghaffarianhoseini et al, 2015). A higher Aspect Ratio can produce a greater percentage of shadow projected over open space which in turn provides the outdoor space with more thermally comfortable hours during the day (Martins et al, 2012).
Sky View Factor (SVF)
Locations with less obstruction of the sky (high value of SVF) can lead to a discomfort of thermal conditions (Krüger et al, 2011; Hwang et al, 2011). The decrease of SVF can reduce air temperature (Ta) by 1.5 0C at 15:00 when the values of SVF are 0.21 and 0.076 (Bourbia and Boucheriba, 2010).
Orientation
A comparison between the two main cases of street and space orientations (North/South, and East/West) was conducted in various studies to show their impacts on outdoor thermal conditions. Most of these studies indicated that North/South orientation of the urban canyon offers better thermal conditions for occupants and buildings envelope (Toudert and Mayer, 2007; Agarwal, 2009; Bourbia and Boucheriba, 2010; Dalman and Salleh, 2011; Andreou, 2013; Shishgar, 2013; Jirón, 2014; and Targhi and Dessel, 2015). Toudert and Mayer (2007) observed that intermediate orientations (North-East/South-West, and North-West/South-East) have some similarity in thermal conditions with North/South orientation and offer shorter time of discomfort than East/West orientation. These orientations were examined with Aspect Ratios 0.5, 1, 2 and 4. Moreover, for courtyards in a hot dry climate, the optimal orientation is North-East/South-West with Aspect Ratio of 1 which provides the courtyard with approximately 60% of shaded area (Ghaffarianhoseini et al, 2015).
Vertical Profile Shape
The asymmetrical profile shape of streets or outdoor spaces can increase the level of shading which in turn contributes to achieving a better outdoor thermal comfort (Toudert and Mayer, 2007; Agarwal, 2009). Different buildings heights can produce better air ventilation within an open space. Moreover adequate openings between streets and courts can also help in obtaining better ventilation which in turn affects energy consumption in buildings and outdoor thermal comfort (Shishgar, 2013).

3.1.4. Buildings Distribution

Compactness
Detached buildings can consume 54% more energy for heating demand and 26% of energy for cooling demand when compared to attached buildings (Ewing and Rong, 2013; Ben Hamouche, 2008). A study in hot arid climate

recorded a reduction of 10.4% of energy consumption for the attached buildings compared to single detached houses (Asfour and Alshawaf, 2015).

Spacing Ratio

The spacing ratio is measured as the ratio of the distance between adjacent buildings and the frontal length of building. The increase of spacing ratio between buildings decreases the potential of shading on facades, which explains the increase of cooling demand. As an example, two cases of housing with the same properties and different spacing ratio 0.1 and 0.8 were examined in terms of energy consumption for cooling demand. The case of 0.1 spacing ratio recorded 27MWh and the case of 0.8 spacing ratio recorded 34MWh (Muhaisen and Abed, 2014).

Buildings Orientation

Abed (2012) demonstrated that arraying buildings in such a horizontal way parallel to the street is preferred and can reduce cooling and heating requirements. Arraying buildings in a horizontal linear way of East/West street can reduce cooling loads by 27.9% and of North/South street by 16.3% compared to singular buildings blocks. An orientation of a building that is slightly East towards South (typically 15° from East to South) is more effective, because in this way the Western façade absorbs lesser sun heat in summer in hot dry climates (Singh and Yadav, 2016).

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3.1.5. Vegetation and Finishing Materials

The characteristics and location of trees are important parameters that determine the amount of solar radiation received by the outdoor space and building facades, as they contribute to increasing the shading, and influencing energy saving in buildings (Calcerano et al, 2016; Sanusi et al, 2016). Deciduous trees (such as live oak, Zelkova, Mimosa, Royal Poinciana) are the most preferable trees in hot arid and hot-humid climates (Ooka et al, 2008; Abdel-Aziz et al, 2015). Also preferred locations are East and West of a building to block direct solar radiation, and South of buildings to block summer solar radiation and allow winter solar radiation (Yekang, 2013; Heisler, 1986). Trees are more effective in mitigation of human heat sensation than lawns (Wang et al, 2016). Adding trees to grass lands can reduce air temperature (Lee et al, 2016). A reduction of approximately 10KWh/m2 can occur as a difference between vf (the ratio of vegetation on the ground)=0.2 and vf=0.8. Also the radius of trees crown (rt) is an effective parameter; a reduction of approximately 20KWh/m2 can occur as a difference between rt=0.2 and rt=0.8 (Wang et al, 2016). Also trunk branching structure, size, and shape of leaves contribute to increasing the cooling effects (Harbich et al, 2015).

Different types of finishing materials vary in its impacts on local micro climate. Reflective materials redirect solar radiation on surfaces and floor which in turn contribute to decreasing heat conduction into buildings that leads to energy savings for indoor cooling load. However reflective materials have opposite effects with regards to outdoor thermal comfort, because the reflected solar radiation increases the temperature of surrounding areas (Pisello et al, 2016). Cool materials can reduce surfaces temperature in shaded area which in turn increases thermal comfort (Taleghani et al, 2016). Increasing surface Albedo can decrease surface temperature (Chatzidimitriou et al, 2015; Erell, 2014). For example in Greece which has an intense problem with heat in summer (high air temperature that exceeds 40^{o}C). Replacing finishing materials by cool materials contributed in decreasing surface temperature by 6.5 ^{o}C, which will have a big influence on microclimate, outdoor thermal comfort and energy consumption in buildings (Dimoudi et al, 2014). Retro-reflective materials redirect solar radiation to the sky in the same direction; however other reflective materials diffuse solar radiation to surrounding space and buildings. Thus, retro-reflective materials are recommended to be used at the roof of buildings (Yuan, 2015).

3.2. Determining Optimal Values of Urban Features for achieving Energy Efficiency and Outdoor Thermal Comfort

In each of the previous studies a set of values of one or more sub-variables of the urban features of open spaces was addressed and its impacts on micro-climate and/or energy consumption were examined. Since both values and variables of urban features are dispersed and diverse, the need arises to comprehensively identify the optimal urban features of open spaces that contribute to reducing energy consumption in buildings and provide outdoor thermal comfort in the context of residential complexes. This paper analyzed the urban features of open spaces (with different variables) at a district level in the context of residential complexes for two climate zones in Egypt (hot-arid and hot- humid). In order to identify the optimal values of urban features that contribute to energy efficiency and outdoor thermal comfort, the following procedures were conducted:

- Comparing values of different sub-variables for urban features of open spaces and their impacts on open space thermal performance and energy consumption in buildings. The comparative analysis of previous studies included: (1) the main urban feature of open spaces, (2) sub-variables of this urban feature, (3) values (based on cases which were examined in previous studies), (4) other related urban features such as pattern, orientation, dimension, building size, etc., (5) simulation variables (climate zone, and time/season), and (6) results which showed the effect of different values on thermal performance of open space in terms of outdoor thermal comfort, and/or energy consumption of buildings. Table 1 shows an example of one of these analyzed studies. The example shows an examination of different Aspect Ratios for non-shaded courtyards in hot humid climate (Ghaffarianhoseini et al, 2015).
- Classification of extracted values for each variable into different sets as illustrated in Table 2. Each set in this classification shares the same urban pattern (according to patterns that are dominantly used in residential complexes) and the same climate zone (according to Köppen climate classification; group B which contains arid and semiarid climates, and group C which contains Temperate climates, Mediterranean climates, Humid subtropical climates, and Oceanic climates (Köppen climate classification).
- A comparative analysis of this classification was conducted in order to identify the optimal value for each urban feature that contributes to energy efficiency and outdoor thermal comfort. An example of the analysis is illustrated in Table 2. For instance, in the set of climate zone group B and linear urban pattern, there are some values of H/W ratio and their different impacts. The analysis is conducted according to identifying the optimal value that results in positive impact in each study (e.g. the optimal value of H/W ratio results in positive air temperature examined in the study). Then, the results were presented in a range from minimum to maximum values.

3.3. Developing a Matrix of Optimal Values of Urban Features of Open Spaces

The extracted results were presented in a matrix format for each of the five main urban patterns that are dominantly used in residential complexes. These five urban patterns include aligned blocks, staggered blocks, courts, staggered courts, and linear blocks as shown in Figure 1 (A to E). The optimal values of the urban features of open space (variables) along with the indicators of energy consumption in buildings and outdoor thermal comfort are presented in Table 3. The results were extracted for each variable into the five main urban patterns in the two climate zones (hot arid, and hot humid). The urban features and their sub-variables include: urban pattern (density), urban canyon (H/W ratio, SVF, and orientation), building distribution (spacing ratio, degree of compactness, and building orientation), and shape of open space (shape and proportions). For example, the optimal aspect ratio was 2:1 in hot arid climate for urban patterns A and B, and a range from 1:1 to 2:1 for urban patterns C, D, and E. However the optimal value of aspect ratio in hot humid climate was 2:1 for urban patterns A and B, and a range from 0.75:1 to 2:1 for urban patterns C, D, and E as illustrated in Table 3.

The values of some variables that were diverse and dispersed in literature are analyzed and grouped in ranges from minimum to maximum values that provide optimal results, such variables include Aspect ratio and Density. However, the values of other variables were identified according to consensus in previous studies and literature, such variables include SVF, Orientation, Degree of compactness, Spacing Ratio, Building orientation, and Space shape. The optimal values of other urban features such as vegetation (optimal type, location, size, features, and fraction of grass to ground) and finishing materials for grounds and buildings have been determined in previous studies and compiled in Table 4

Table 1: An example analyzing the literature: an examination of different Aspect Ratios for non-shaded courtyards in hot humid climate.

1	2	3	4			5		6	
Urban Features	Sub-Variables	Values	related variables (other urban features)			simulation items		Results	
								Thermal Performance	
								Solar Radiation	
			orientation	urban pattern	other related sub-variables	climate zone	season/ time	walls	ground
Urban canyon	shallow H/W<1	0.16:1	facing North	court	a court in U-shape building with dimensions with 24*24 m	hot- humid	summer	direct solar radiation 0-950 w/m2 from 8:00 to 19:00, zero the rest of day time hours	at 15:00 (31.8 °)C
		0.5:1	facing North	court	a court in U-shape building with dimensions with 24*24 m	hot- humid	summer	direct solar radiation 890-950 w/m2 from 10:00 to 17:00, zero the rest of day time hours	at 15:00 (31.7°) C
	uniform H/W=1	1:1	facing North	court	a court in U-shape building with dimensions with 24*24 m	hot- humid	summer	direct solar radiation 920-950 w/m2 from 11:00 to 16:00, zero the rest of day time hours	at 15:00(31.2°) C

classification according to climate zone

classification according to urban pattern

Table 2. Classification & Analysis

Urban canyon (Aspect ratio) for streets/ main spaces							
Reference	**Climate Zone**	**Urban pattern**	**Orientation**	**Aspect Ratio H/W**	**Effect of aspect ratio on: Issue**	**Results**	**Optimal H/W <range>**
Jirón, etal, 2014	Semi-Arid	Linear	N/S	1:1	solar radiation (kwh/m2)	6.30	1:1 - 2:1
Toudert and Mayer, 2007	Hot Dry	Linear	N/S	2:1	Air Temperature ^{0}C	36.9	
				1:1		38.5	
				0.5:1		39.3	
Dalman and Salleh, 2011	Hot Humid	Linear	N/S	1:1	Thermal comfort PET ^{0}C	53.7	0.75:1- 2:1
				0.5:1		56.3	
Targhi and Steven, 2015	Humid Continental	Linear	N/S	1.75: 1	Thermal comfort PET ^{0}C	15	
				2:1		50	
Nguyen Van etal, 2014	Hot Humid	Linear	N/S	0.75: 1	Energy cost $/sqm floor	19	
				1.5:1		20	
Andreou, 2013	Mediterranean	Linear	N/S	2:1	Thermal comfort PET C	27.5	
				1:1		28	
				0.8:1		29	
				0.6:1		35	
Allegrini etal, 2015	Oceanic Climate	Linear	E/W	1:1	North facades temperature C	26	
				2:1		25	

Optimal value of H/W that provides minimum solar radiation in this study

Optimal value of H/W that provides minimum air temperature in this study

Range of optimal H/W ratios

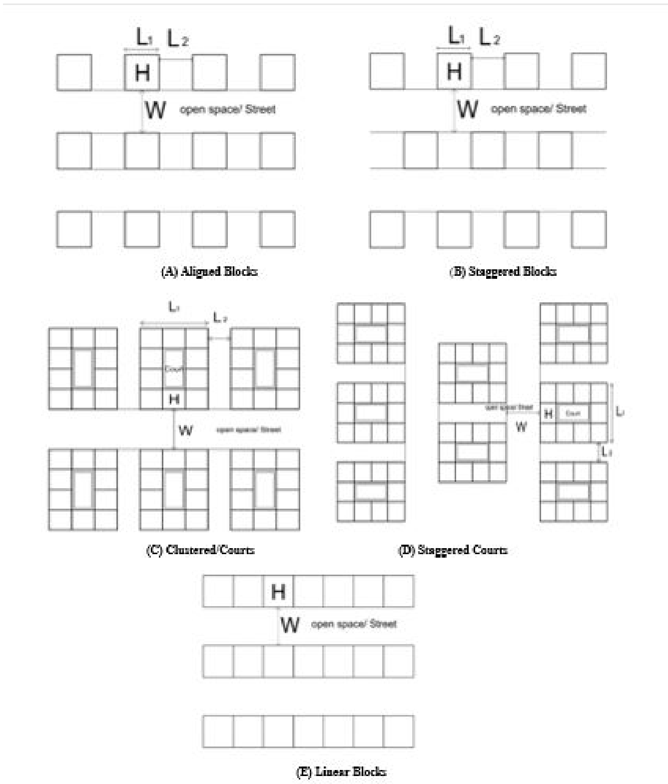


Figure 1. Most dominantly used urban patterns in residential complexes.

Table 3. Matrix of optimal values [extracted from results of previous studies] of urban features of open spaces for achieving energy efficient buildings and outdoor thermal comfort in residential complexes.

		Climate Zone	Urban Patterns as shown in Figure 1				
			A	B	C	D	E
Urban Features of Open Spaces	Urban Canyon		Aspect Ratio				
		Arid	2:1		1:1-2:1		
		Hot-Humid	2:1		0.75:1-2:1		
			SVF for streets and main spaces				
		Arid	0.2				
		Hot-Humid	For N/S 0.3 for E/W 0.7				
			Orientation for streets or main spaces				
		Arid	N/S	N/S	N/S		
		Hot-Humid	E/W	E/W	N/S		
	Urban Pattern		Density (du./1000 m²)				
		Arid	3-4				
		Hot-Humid	2-2.5				
	Building Distribution		Degree of Compactness				
		Arid	3 sided				
		Hot-Humid					
			Spacing Ratio				
		Arid	0.1				
		Hot-Humid	0.1				
			Building orientation (according to street/space)				
		Arid	Long axis: E/W – slightly East of South (typically 15° east of South)				
		Hot-Humid					
	Shape of Open Space		Court shape and proportions				
		Arid	Square 1:1:1				
		Hot-Humid	Square 1:1:1 Rectangular 1:1.5:1 For central shapes: at R1=1, the optimal shape is pentagonal followed by other polygons then circular While R1 is the ratio of the courtyard's floor perimeters P to the form's height H				

4. Results and Discussion

The results of optimal urban features of open spaces and their corresponding values are presented in a guide as illustrated in Table 5 that can be used to help designers and planners to design open spaces in residential complexes that can have thermal comfort in the outdoor along with buildings that use less energy consumption. This energy and comfort based urban design guide provides optimal settings of urban features of open spaces in a systematic manner to overcome diversity and dispersion for variables of urban features encountered in previous studies. The urban features of open spaces and their optimal values were extracted from previous studies and categorized into five main urban patterns of residential complexes (Blocks, Staggered, Courts, Staggered Courts, and Linear) in the two climate zones of hot arid and hot humid. The energy and comfort based urban design guide presented in Table 5 can be viewed as a useful start-up during the early design phase to help designers to appropriately formulate their designs from energy and comfort perspectives before getting into detailed design phases. This guide provides a combination of main urban features of open spaces with different sub-variables and optimal values that help to achieve energy efficiency in buildings, and outdoor thermal comfort.

At the early design phase, a designer/architect composes the shape and form of the conceptual idea according to the project type, site conditions, user requirements, design standards and regulations along with many other issues. The design composition includes the type of urban pattern. The conventional approach of formulating the design composition of residential complexes is heavily dependent on the accumulated personal design experience and preferences of the designers and planners. The evaluation of energy efficiency and thermal comfort of such design composition is usually conducted at later times during the detailed design phases. However, it is much more effective and beneficial to inform designers at the early design phase of the various possibilities and alternatives than can be used while formulating design compositions to achieve energy efficient and comfortable design solutions.

Table 5: urban Design guide of open spaces in Residential complexes: selection of optimal values of urban features for achieving energy efficient buildings and outdoor thermal comfort in five patterns of residential complexes

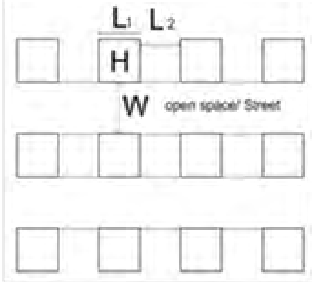
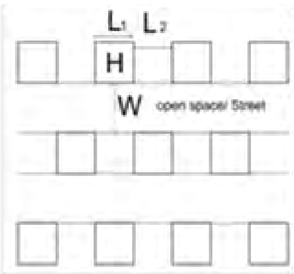
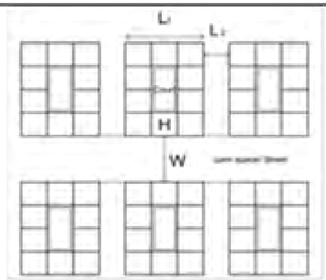
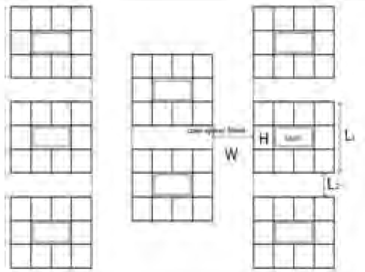
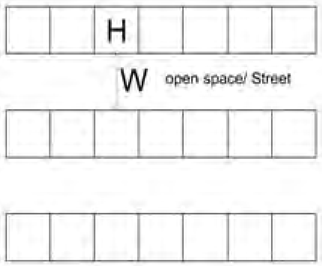
Pattern of open spaces in residential complexes		Climate zone	Values of urban features of open spaces in residential complexes							
			Urban canyon			Density	Building Distribution			Space shape
			Aspect ratio	SVF	Orientation	du./1000 m2)	Degree of compactness	Spacing ratio L_1/L_2	Building Orientation	Shape And proportions
Blocks		Hot Arid	2:1	0.2	N/S	3-4	3- sided	0.1	long axis : E/W - slightly east of south (typically 15° east of south)	Square: 1:1:1 Rectangular: 1:1.5:1 For central shapes at R1*=1 the optimum shape is pentagonal then other polygons then circular
		Hot Humid	2:1	for N/S 0.3 ,for E/W 0.7	E/W	2-2.5	3- sided	0.1		
Staggered		Hot Arid	2:1	0.2	N/S	3-4	3- sided	0.1	long axis : E/W - slightly east of south (typically 15° east of south)	Square: 1:1:1 Rectangular: 1:1.5:1 For central shapes at R1*=1 the optimum shape is pentagonal then other polygons then circular
		Hot Humid	2:1	for N/S 0.3 ,for E/W 0.7	E/W	2-2.5	3- sided	0.1		
Courts		Hot Arid	1:1-1:2	0.2	N/S	3-4	3- sided	0.1	long axis : E/W - slightly east of south (typically 15° east of south)	Square: 1:1:1 Rectangular: 1:1.5:1 For central shapes at R1*=1 the optimum shape is pentagonal then other polygons then circular
		Hot Humid	0.75:1-2:1	for N/S 0.3 ,for E/W 0.7	N/S	2-2.5	3- sided	0.1		

Table 5: urban Design guide of open spaces in Residential complexes: selection of optimal values of urban features for achieving energy efficient buildings and outdoor thermal comfort in five patterns of residential complexes.

Pattern of open spaces in residential complexes		Climate zone	Values of urban features of open spaces in residential complexes							
			Urban canyon			Density	Building Distribution			Space shape
			Aspect ratio	SVF	Orientation	du./1000 m2)	Degree of compactness	Spacing ratio L_1/L_2	Building Orientation	Shape And proportions
Staggered courts	 	**Hot Arid**	1:1-1:2	0.2	N/S	3-4	3- sided	0.1	long axis : E/W - slightly east of south (typically 15° east of south)	Square: 1:1:1 Rectangular: 1:1.5:1 For central shapes: at R1*=1 the optimum shape is pentagonal then other polygons then circular
		Hot Humid	0.75:1-2:1	for N/S 0.3 ,for E/W 0.7	N/S	2-2.5	3- sided	0.1		
Linear	 	**Hot Arid**	1:1-1:2	0.2	N/S	3-4	3- sided	0.1	long axis : E/W - slightly east of south (typically 15° east of south)	Square: 1:1:1 Rectangular: 1:1.5:1 For central shapes: at R1*=1 the optimum shape is pentagonal then other polygons then circular
		Hot Humid	0.75:1-2:1	for N/S 0.3 ,for E/W 0.7	N/S	2-2.5	3- sided	0.1		

5. Conclusion

This paper introduced a categorization for the impacts of each of the urban features of open spaces (urban pattern, urban canyon, building distribution, and shape of the open space) on both energy consumption and outdoor thermal comfort along with the impacts of vegetation and finishing materials. Also, values for each of the urban features of open spaces were compared and classifications of these values based on their impacts on both energy consumption and outdoor thermal comfort were developed in order for optimal values of urban features to be identified. A matrix was developed to represent the optimal features of open spaces along with their associated impacts on both energy consumption and outdoor thermal comfort. The urban features of open spaces and their optimal values were categorized into five main urban patterns of residential complexes (Blocks, Staggered, Courts, Staggered Courts, and Linear) in the two climate zones of hot arid and hot humid and can be used as an energy and comfort based urban design guide.

Designers and urban planners can use the developed energy and comfort based urban design guide based on the climate zone and their preferred urban patterns of residential complexes (e.g. Blocks, Staggered, Courts, Staggered Courts, and Linear) to select the most appropriate urban features including urban canyon, density, building distribution, and space shape and their sub-features that will help in achieving energy efficient and comfortable outdoor spaces. The appropriateness of such urban features is ensured by not exceeding the values and ranges identified in the energy and comfort based urban design guide which are based on extracted resulted from previous studies for achieving outdoor thermal comfort and energy efficient buildings.

However, there is a need to enrich the energy and comfort based urban design guide developed and presented in this paper by specific and quantifiable measures of achieving energy efficiency and outdoor thermal comfort for each of the recommended optimal values of each of the urban features of open spaces. Therefore, detailed energy simulation and microclimate analysis of the dominant urban patterns of residential complexes including the optimal urban features and corresponding values are required to be conducted, which is planned to be pursued as a future work of this research.

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