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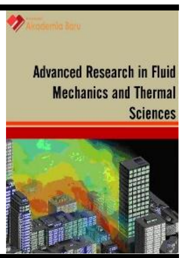

Comparative Analysis of Housing Cluster Formation on Outdoor Thermal Comfort in Hot-arid Climate

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ABSTRACT

Recent literatures have addressed the effect of building formation on outdoor thermal comfort at urban scale level in various environmental climate contexts. However, there is a research gap in studying the effect of housing clusters formation in specific climate context for Baghdad city as an example of hot arid climate, and its effects on the outdoor thermal comfort. This research aims to comparatively analyze and simulate different housing cluster formations in terms of height, contiguity, and grouping of buildings and their effect on outdoor thermal comfort city using ENVI-MET 4.4.2 software. The simulation depends on several parameters analyses that include Predicted Mean Vote (PMV), mean radiant temperature, air temperature, humidity, and air speed. The results of this research found the optimized building formation which improves microclimate thermal comfort on the pedestrian level for hot arid climate.

1. Introduction

There was massive shortage for housing buildings in Baghdad city, the high prices of land within urban areas, the continuous increase in population, and the recent National Housing Policy in Iraq had largely encouraged the private sector to invest in multi-story housing projects. Consequently, since 2010, all residential investment projects in Baghdad, had been constructed as high-rise (9 stories and above). Nonetheless, the rising temperature on a global scale, especially in regions with hot arid desert climate, such as Baghdad, due to proximity to the equator and the prolonged exposure to sun radiation throughout the year, had made necessary the inclusion of environmental aspects and thermal comfort in the design of buildings and open spaces. Previous research provided numerous literatures on the aspects related to the effect of buildings design and materials on indoor thermal comfort [16,17,18], or the effect of buildings materials, formation, and street to buildings height ratio on outdoor thermal comfort [2,4,6]. However, the impact of the differences in building heights, geometries, and grouping patterns on outdoor thermal comfort indexes in the city

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of Baghdad, as an example of hot arid climate, had not been addressed in a statistical way. For instance, analyzed the relationship between the geometry of urban canyon and the radiance of solar light and studied the effect of the height of building and street width in shading of ground and the surface of street for different orientations in urban complex in Algeria specifically in El-Qued city [1]. The study compared between traditional and modern district dependent on the geometry and orientation of canyon and the sky line factor also the material covered the street which showed that all increased in height of building the temperature of its surface will be increased, also the black asphalt street more warmer the climate than the sandy traditional one, the orientation of east-west elevation was warmer than north-south in canyon. The study recommends the designer to create shading by planting and shading devices in the essential urban design and reduce the height of building to reduce the irradiation of direct sun light all the day time, this procedure will reduce the harshness of hot dry climate [2]. Studied the effect of geometric formation on achieving thermal comfort of pedestrians by comparing the space of two types of streets, the wide street and deep street represented by the traditional planning types in Morocco. The study adopted field measurements in summer season using PET index to measure thermal comfort. It showed that traditional deep street achieved better results in terms of thermal comfort for it had lower recorded temperatures. In another study, studied the positive and negative effect of using asymmetrical street aspect ratio in hot humid regions and its effect on the micro climates, the analyzing depend on the boulevard component which must be asymmetry in the two sidewalks and the importance of providing the shading in trees and building design, also the study ensure the that the west south elevation more warmer than the opposed side of the street in the day time [3]. Pointed out the importance of urban spaces in achieving thermal comfort and reducing urban heat island effect in dry hot climate [4].

Yet, it focused specifically on the context of Algeria. And it relied on using ENVI-MET 3 for the modeling of data and the simulation of a number of urban spaces within a street in the city of Ghardaia. The results showed the effect of street width to height, shading, tree-planting and street orientation in achieving thermal comfort. Evaluated the thermal comfort of the outdoor spaces in hot dry climate in Haifaa street in Bagdad through the using the software of ENVI-met which analyzed the most hottest day in summer which the degree over 50°C and conclude away to lowering the temperature about 10.4°C and 2.4°C in PET [5]. By the study of the four factors that effect on the thermal comfort in urban area which is planting cover, the geometry of canyons, spacing between buildings and shading devices, which the urban planner should take it into account before the designing of new urban complex. Highlighted the importance of an urban design which corresponds with local environment within cities and takes into consideration the characteristics of urban form in squares, fields, and streets (the coefficient of sky vision and density of buildings on the edges of the vacuum) [6].

The study also emphasized the role of morphological variables of the squares and fields that include (The elevation ratio of the sky, the visibility factor of the sky and the shape of the lateral sector) in a preliminary assessment of thermal performance of external urban spaces in order to achieve the most compatible environmental design techniques. Yet, it was specific to the context of Egyptian cities. Therefore, there is a need to study and analyze the correlation between urban geometry formation and thermal comfort within the specific context of Baghdad, and especially within Housing Cluster Formation. Examined the effect of urban block and street formation with the combination of river width on thermal comfort for the pedestrian level in Melaka City, Malaysia [7]. The research compares between different street and water width with different direction. The results showed that effect of each tested parameters on the thermal comfort for the city environment.

2. Methodology

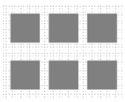
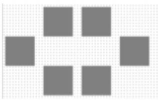
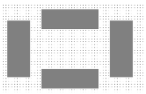
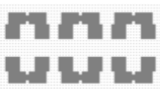
The methodology of this research relied on a computer simulation program ENVI-MET Headquarter V4.4.2 Winter 1819, the program developed recently to simulate the microclimate conditions that include (PMV, Air temperature, Wind speed and direction, Sun radiation, Vegetation effect, and many others). To analyze the effect of five common formations and grouping patterns of residential buildings on thermal comfort in Baghdad [8-10]. These formations included, linear pattern of separate short blocks (20 x 20 m), long blocks (40 x 20 m), and fragmented blocks (30 x 20 m), as well as shared courtyard grouping pattern of short and long blocks. Each of these formations was analyzed in three scenarios, low-rise (3 stories, 10 m), mid-rise (6 stories, 18 m), and high-rise (10 stories, 30 m). In 2018, the Urban Housing Standards in Iraq categorized residential buildings into: low-rise (2-4 stories), mid-rise (5-8 stories), and high-rise (9-12 stories). For low-rise and mid-rise buildings, the distances between the front elevations and side elevation were set to be 12 meters and 6 meters, respectively. For high-rise buildings, the distances between the front elevations and side elevation were set to be 18 meters and 8 meters, separately. The heights of the proposed buildings and distances between them are based on the Urban Housing Standards in Iraq. An urbanized area in Baghdad was chosen [11]. Baghdad is a capital of Iraq, it located in latitudes between 29-37°N. Baghdad climate classified as semiarid region. The maximum temperature reached to 50°C in summer time. Night temperatures in summer are occasionally below 24°C. Relative humidity is lower than 40% in summer time. Winter average temperatures 15-18°C. Climate changes are apparent in Baghdad and Iraq as while, there is rising in temperature from 1950 annually of 0.7°C per decade. And it is predictable to rising to 2.2°C, in 2050 compared to 1900 [12, 13].

The rise of multi-family housing programs in Baghdad dates back to 1965 during which a major housing program was elaborated by Polservice consulting engineers which proposed single-family residential units as well as multi-story housing. Nonetheless, it took more than a decade for this program to see the light. The construction of residential projects started during the late 1970s and continued throughout the 1980s. These projects had left a great impact on the horizontal cityscape of Baghdad city which was dominated by single-family housing [14, 15].

In terms of their geometry, these residential projects varied from low-rise (3-4 stories) such as Zayona project and Saidiya project, to mid-rise (8 stories), to high-rise (15 stories) such as complex no.8 in Haifa project. Their forms included relatively short, separated blocks with flat facades such as complex no.8, long continuous blocks such as Sadiya project and Abu Nuwas project, and fragmented facades such as Salhiya project. The grouping patterns also varied to include linear pattern and shared court pattern.

Multi-story housing projects returned to appear in the urban context of Baghdad after 2004. Nevertheless, a close examination of their geometry indicates that there is a high tendency by investors towards constructing high-rise projects (9 stories and above) such as Ayadi project and Zuhur Baghdad project. A very limited number of projects which are currently under construction were designed and constructed as low-rise projects. These include Sab'abkar project (3 stories) and Shams project (2 stories). Therefore, there is a need to explore the impact of these different heights, geometries, and patterns on thermal comfort on the pedestrian level in order to find out the optimized design for residential projects and whether or not the current trend of high-rise separate blocks is environmentally suitable for the hot-arid climate of Baghdad. In an attempt to address the most common patterns and building geometries of the existing residential projects in Baghdad, the simulation encompasses five categories of residential projects. These categories are shown in Table 1 below.

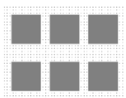
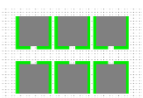
Table 1
Attributes of analyzed typologies

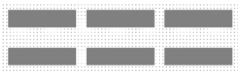
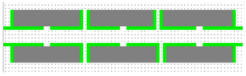
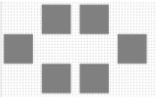
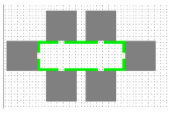
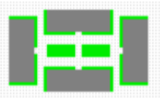
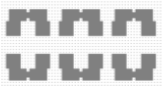
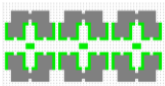
Pattern Type	Grouping pattern	Height type	Surface area (m²)	Ground floor area (m²)	Height (m)	Floor-Area Ratio (FAR)	Site area (m²)	Material
 Type A  Type B	Linear	Low-rise Mid-rise High-rise	6000 10800 18000	2400 2400 2400	10 18 30	1.107 2.215 3.692	6500 6500 6500	Concrete with Moderate insulation
 Type C  Type D	Central with a Shared court/public spaces	Low-rise Mid-rise High-rise	6000 10800 18000	2400 2400 2400	10 18 30	1.107 2.215 3.692	6500 6500 6500	Concrete with Moderate insulation
 Type E	Linear with U-shape Form with fragmented facade	Low-rise Mid-rise High-rise	6000 10800 18000	2400 2400 2400	10 18 30	1.107 2.215 3.692	6500 6500 6500	Concrete with Moderate insulation

3. Results

ENVI-MET Headquarter V4.4.2 makes possible to simulate various indexes related to thermal comfort within various geometries and patterns. As mentioned above, the analysis encompassed five indexes: PMV, mean radiant temperature, air temperature, relative humidity, and wind speed. These indexes were simulated for the most common patterns and geometries of residential projects in Baghdad which were divided into five categories as shown in Table 1. The simulation results are shown in Table 2 and 3.

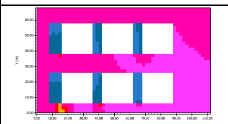
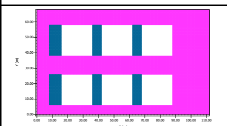
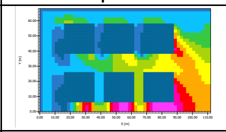
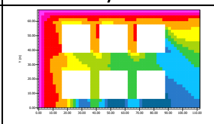
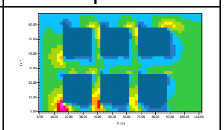
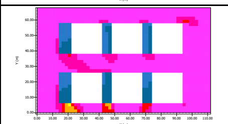
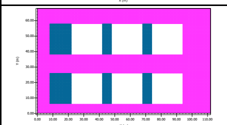
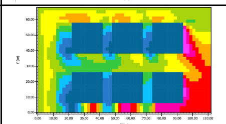
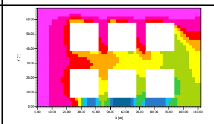
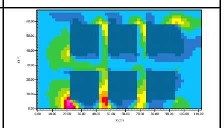
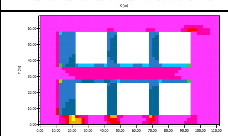
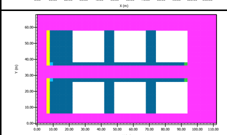
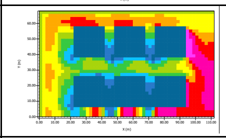
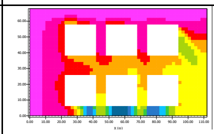
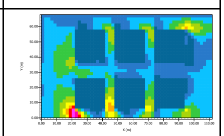
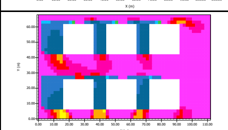
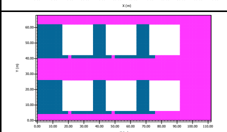
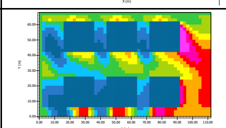
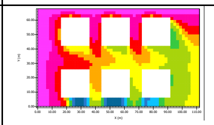
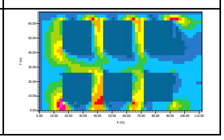
Table 2
Minimum and maximum parameters of analyzed indexe

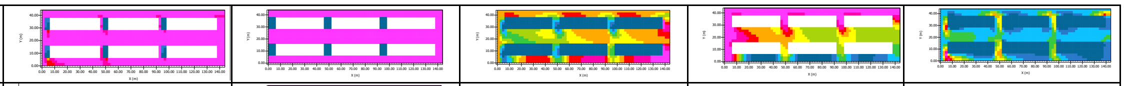
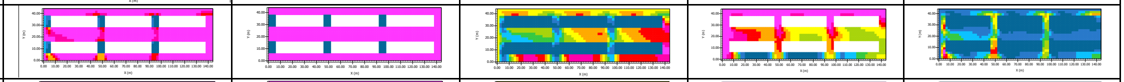
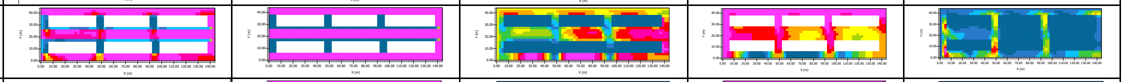
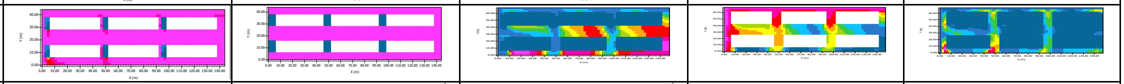
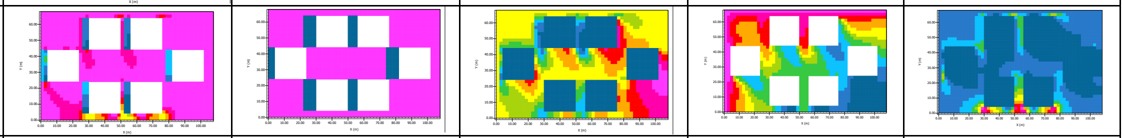
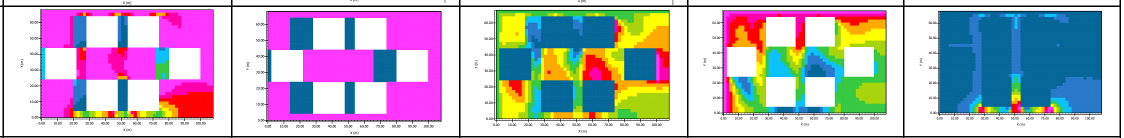
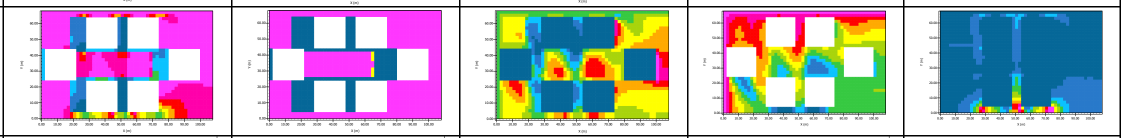
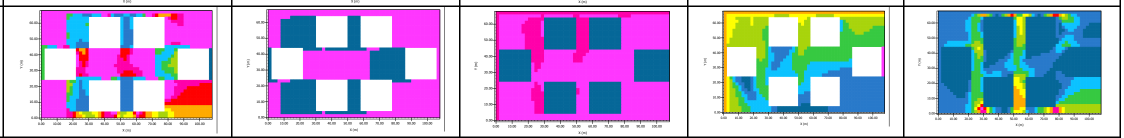
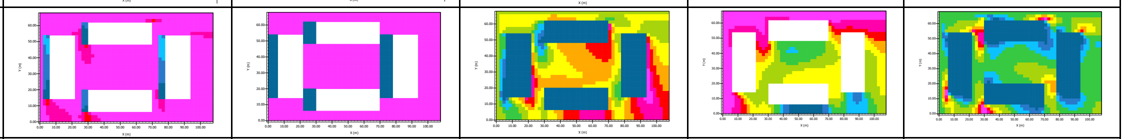
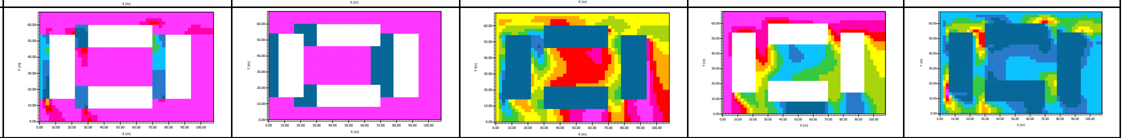
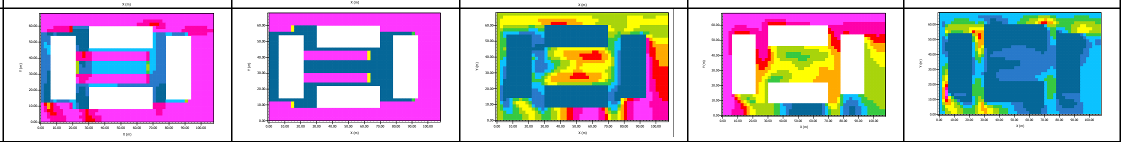
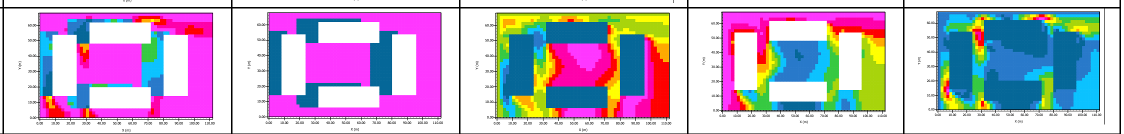
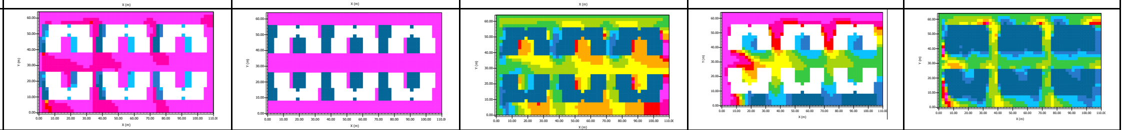
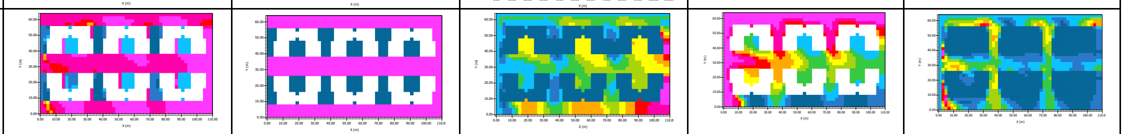
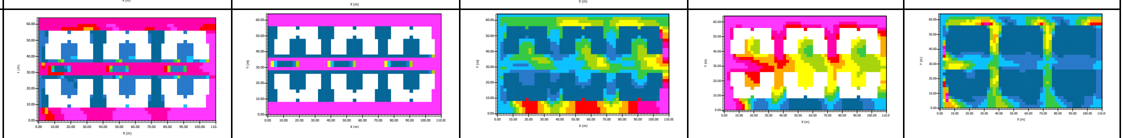
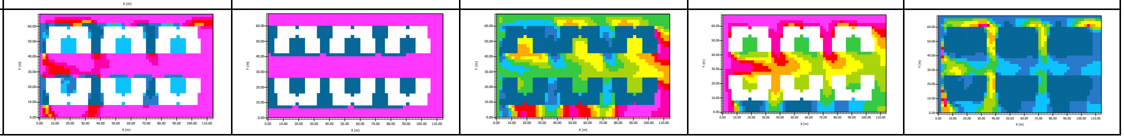
Pattern type		PMV		Mean radiant temperature Celsius		Air temperature Celsius		Relative humidity (%)		Wind speed m/s	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Type A	LR	0.9	3.09	29.03	60.28	25.94	27.85	60.8	77.2	0.07	3.08
	MR	1.76	3.86	28.31	59.77	28.80	30.38	61.3	75.0	0.08	4.12
	HR	1.64	3.79	27.92	59.60	28.58	30.21	62.1	75.0	0.02	5.12
MR With plants 		1.58	3.76	26.73	58.97	28.30	30.18	61.4	75.0	0.04	4.47

Type B	LR	1.91	3.92	28.90	60.11	29.17	30.48	61.7	75.0	0.05	3.40
	MR	1.75	3.86	35.20	63.73	28.99	30.45	59.8	75.0	0.09	5.21
	HR	1.64	3.79	35.92	64.10	25.65	28.28	58.0	77.1	0.02	8.53
MR With plants 		1.56	3.77	26.06	59.03	28.43	30.21	59.2	75.0	0.01	5.69
Type C	LR	1.86	4.01	29.51	61.18	28.98	30.74	60.8	75.0	0.02	6.29
	MR	1.70	3.94	28.63	60.69	28.69	30.53	60.7	77.1	0.01	14.8
	HR	1.29	3.78	27.60	60.05	19.86	29.93	59.9	87.1	0.00	7.01
MR With plants 		1.66	3.89	28.01	59.83	28.64	30.48	60.7	77.2	0.02	14.4
Type D	LR	1.97	3.98	29.63	61.59	28.99	30.60	62.7	75.0	0.04	2.68
	MR	1.82	3.90	29.09	60.98	28.81	30.40	62.8	75.0	0.08	3.75
	HR	1.68	3.83	35.54	64.44	28.53	30.17	62.7	75.0	0.04	4.96
MR With plants 		1.63	3.76	27.21	59.22	28.49	30.24	62.6	75.0	0.04	3.84
Type E	LR	1.95	4.0	28.92	61.11	29.04	30.80	63.9	75.0	0.01	2.70
	MR	1.75	3.93	27.61	58.94	28.78	30.78	62.0	75.0	0.02	3.77
	HR	1.64	3.77	27.30	58.82	28.65	30.23	61.1	75.0	0.01	5.15
With plants 		1.58	3.79	24.79	58.35	28.22	30.52	61.7	75.0	0.02	3.49

LR: low-rise (3 stories, 10 m), MR: mid-rise (6 stories, 18 m), HR: high-rise (10 stories, 30 m), Min: minimum value, Max: maximum value.

Table 3
The results of 2D map simulation using ENVI-met

Type	PMV	MRT	Air Temperature	Humidity	Wind speed
A-LR					
A -MR					
A-MR with plants					
A-HR					

B-LR	
B-MR	
B-MR with plants	
B-HR	
C-LR	
C-MR	
C-MR with plants	
C-HR	
D-LR	
D-MR	
D-MR with plants	
D-HR	
E-LR	
E-MR	
E-MR with plants	
E-HR	

Legend	PMV	Mean Radiant Temp.	Air temperature	Relative Humidity	Wind Speed
	below 1.97	below 29.36 °C	below 28.97 °C	below 63.87 %	below 0.42 m/s
	1.97 to 2.18	29.36 to 32.66 °C	28.97 to 29.13 °C	63.87 to 65.11 %	0.42 to 0.80 m/s
	2.18 to 2.39	32.66 to 35.95 °C	29.13 to 29.29 °C	65.11 to 66.36 %	0.80 to 1.18 m/s
	2.39 to 2.60	35.95 to 39.25 °C	29.29 to 29.45 °C	66.36 to 67.61 %	1.18 to 1.56 m/s
	2.60 to 2.81	39.25 to 42.55 °C	29.45 to 29.60 °C	67.61 to 68.85 %	1.56 to 1.94 m/s
	2.81 to 3.02	42.55 to 45.84 °C	29.60 to 29.76 °C	68.85 to 70.10 %	1.94 to 2.32 m/s
	3.02 to 3.23	45.84 to 49.14 °C	29.76 to 29.92 °C	70.10 to 71.35 %	2.32 to 2.70 m/s
	3.23 to 3.44	49.14 to 52.44 °C	29.92 to 30.08 °C	71.35 to 72.59 %	2.70 to 3.08 m/s
	3.44 to 3.65	52.44 to 55.73 °C	30.08 to 30.24 °C	72.59 to 73.84 %	3.08 to 3.46 m/s
	above 3.65	above 55.73 °C	above 30.24 °C	above 73.84 %	above 3.46 m/s

These images include all five indexes for the five types of geometric formation in three scenarios for each type. The results indicated that, the differences in building heights, geometries, and grouping patterns had a significant impact on thermal comfort indexes (PMV, Mean radiant temperature, Air temperature, Relative humidity, Wind speed) as shown in Figure 1-5.

The lower PMV for low rise buildings was Type (A), the worst results for the types (C and E). While the best results for the Midrise buildings were types (B and A), the worst result were types (D and E). The best results for the High rise buildings was type (E), the worst result was type (D).

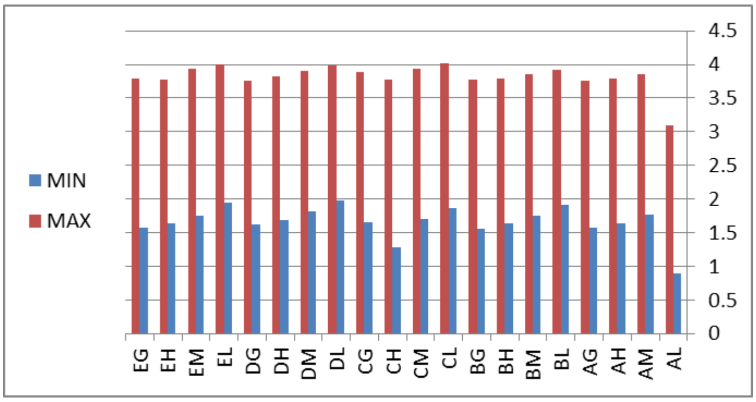


Fig. 1. Comparison of maximum and minimum PMV index for each grouping types

Fig. 2. Comparison of maximum and minimum mean radiant temperature index for each grouping types

The highest mean radiant temperature indexes for low rise buildings were Type (D), the worst results for the type (B). While the best results for the Midrise buildings were types (E and A), the worst result was type (B). The best results for the High rise buildings were type (E), the worst result was type (D).

Fig. 3. Comparison of maximum and minimum air temperature index for each grouping types

Fig. 4. Comparison of maximum and minimum relative humidity index for each grouping types

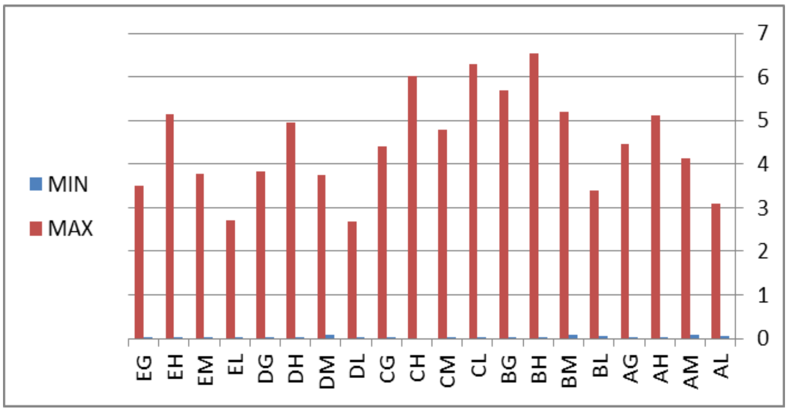


Fig. 5. Comparison of maximum and minimum wind speed index for each grouping types

The highest air temperature for low rise buildings was the type (E), the best results for the type (A). While the best result for the Midrise buildings was the types (A), the worst result was the type (E). The best results for the High rise buildings was type (D), the worst result was type (C).

The highest relative humidity for low rise buildings was the type (A), the lower results for the type (B). While the higher result for the Midrise buildings was the types (C), the lower result was the type (B). The higher result for the High rise buildings was the type (C), the lower result was the type (B).

The highest wind speed for low rise buildings was the type (C), the lower results for the type (D). While the higher result for the Midrise buildings was the types (B), the lower result was the type (D). The higher result for the High rise buildings was the type (B), the lower result was the type (D).

The total results indicated that according to grouping Pattern Type: buildings type (A) of low rise and midrise buildings had achieved best results. While the type (E) of high rises buildings achieved best results. Also results indicate that according to buildings height: low rise had achieved best results than midrise buildings.

In addition, the inclusion of greenery and plants within the open spaces of residential projects had a significant impact on the parameters of thermal comfort indexes. The reduction in these parameters ranged between (0.09 – 0.18) degrees for PMV, (0.59 – 9.14) degrees for mean radiant temperature, (0.16 – 0.56) degrees for temperature, (0 – 0.63) for humidity. See Table 2 above for details.

4. Conclusions

Although the recently constructed high-rise housing projects in Baghdad might have the benefit of reducing housing shortage in a crowded city for they provide a higher number of residential units in smaller area compared to low-rise and mid-rise buildings, yet, the simulation conducted in this research indicated that they have dramatic impact on thermal comfort indexes. The results of this research found that the linear types and U-shape buildings had the highest values of thermal comfort. Also the research indicated that low-rise (2-4 stories) and mid-rise (5-8 stories) residential buildings provide better thermal comfort on the pedestrian level within the public spaces of residential projects constructed in the densely urbanized areas of Baghdad which is known for its hot-arid climate. In the other hand, the long, continuous residential blocks had the lowest thermal comfort, whether they were grouped in a linear pattern or a shared-court pattern. The simulation of the shared court pattern indicated that the increase in the distance between the front facades as well as the increase in the area of the open shared spaces within residential projects decreases thermal comfort on the pedestrian level. This simulation also showed that the inclusion of plants and green surfaces within the shared open spaces of housing complexes has a significant impact on increasing thermal comfort. Nonetheless, this research proposed several constants within the simulation, such as the façade materials, and thus, further research is required to analyze and explore the impact of variations applied to these constants in order to further optimize the design of residential projects in the hot-arid climate of Baghdad to achieve higher levels of thermal comfort.

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