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Original Research

ADOPTING A SUSTAINABLE URBAN DESIGN TO IMPROVE THERMAL COMFORT IN AN ARID CLIMATE

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Abstract: Greenery strategies and shaded pedestrian passages have become requirements for designing smart cities in developed countries. One of the most difficult challenges for designers is designing cities in hot and arid climates while maintaining a proper level of outdoor thermal comfort. The designers focus on creating a comfortable climate for people throughout the afternoon under the hot sun, particularly in countries where summer temperatures rise excessively for more than seven months per year, as in Iraq. This study compares two Baghdad cities: Haifa Street, which was built in 1984 on a Western design pattern, and the second city, which the researchers designed according to the requirements of construction in an arid climate, such as street and building orientation, aspect ratio, sky view factor, the influence of courtyards, and the role of albedo. The second city is planned to cover the same total area as the first. The results of the two cities were compared and analyzed using ENVI-met software. To conduct a comparison between the two cities on a typical summer day, two indices, PMV and Tmrt, were used. The results showed that the proposed new city design reduced Tmrt and PMV, contributing to improved thermal comfort. The proposed design reduced the Tmrt value in the model by 10.5°C in proportions of 90% of the total urban area. Furthermore, the suggested design offers superior thermal values on a typical summer day than Haifa Street.

Keywords: *Greenery strategies; urban heat island; outdoor thermal comfort; aspect ratio; sky view factor; ENVI-met; mean radiant temperature (Tmrt); predicted mean vote (pmv).*

1. Introduction

As one of the driest regions most susceptible to climate change, Iraq faces several environmental issues. Only limited efforts were made in scientific studies to suggest techniques for mitigating Urban Heat Island impacts and enhancing the outdoor thermal comfort of pedestrians in a dry region[1]. The frequency and severity of extreme weather events, more frequent and severe dust storms, environmental degradation throughout Iraq, droughts, and unusually high temperatures have all recently increased due to climate change. The relationship between the urban fabrics (natural materials and construction), ground cover (pavement, vegetation, built-up, water, and soil), urban structure (building dimensions and aspect ratio), and urban metabolism (water, heat, and human activity pollutants) specifies how the urban climate changes [2]. As a result, the effects of mitigation measures are difficult to assess[3]. According to numerous references, urban structure, and urban fabric are crucial parts of urban design in arid climate conditions. As a result, the researchers proposed the

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following essential factors related to the effect of urban and fabric structure in urban design, particularly in hot and arid climates:

1.1. Urban and fabric structure

1.1.1. *Aspect ratio.*

1.1.2. *Street and buildings orientation.*

1.1.3. *Sky view factor.*

1.1.4. *Influence of colonnades.*

1.1.5. *Influence of courtyards.*

1.1.6. *Means of shading.*

1.1.7. *Role of the albedo.*

we address the most critical factor affecting urban and fabric structure in hot, arid climates, such as:

1.1.1. Influence of aspect ratio

A study comparing the thermal efficiency of traditional and contemporary residential urban canyons was carried out in Riyadh's arid and hot city (Saudi Arabia). The study found that the aspect ratio H/W and the canyon's orientation determine how exposed urban surfaces are to solar radiation. It was shown that daytime ambient temperatures are more significant in shallow contemporary canyons with H/W =0.42 than in deep traditional canyons with H/W =2.2 [4]. Alaoui et al. [5] conducted an investigation study in Morocco. The aspect ratio (H/W>2) raises cooling energy consumption because of the increased thermal recession and the impact of poor ventilation.

1.1.2. Influence of street orientation

One of the most crucial elements affecting the quantity of solar radiation on pedestrian pathways is street orientation. Ridha found that narrow pedestrian pathways are crucial for enhancing thermal comfort as they provide diurnal shadowing and reduce the amount of heat generated by the surface[6]. In hot, dry regions, rotating the roadway to the NE-SW or NW-SE results in superior comfort conditions, according to Ali-Toudert and Mayer [7]. This happened as a consequence of the walls' more potent shading effects as opposed to an E-W orientation, which decreased exposure to direct sunlight due to shadow. According to the 1982 "Polservice" publication "Iraqi Housing Technical Standards" and "Codes of Practice Report", the orientation of buildings in hot-dry zones favors within 350 South-East is advised. The buildings might be extended along an East-West axis, with 250 South-East being the ideal balance[8].

1.1.3. Sky view factor

The impact of shade on mean radiant temperature (Tmrt) reduces dramatically as solar radiation decreases. As a consequence, as shown in Fig. 1, broad canyons in the city's new part are less pleasant with maximal Tmrt and PET than are curvy walkways in the old Aleppo[9].

Figure 1. View of the new and old Aleppo districts in three dimensions [9].

1.1.4. Influence of Colonnades

The comfort of buildings is increased by colonnades (arcades) on the ground floor. Due to their position on the south side of an E-W-oriented roadway, the colonnades face north. This approach increases the amount of shadow along the roadway and reduces the amount of sunlight that reaches the ground[6].

1.1.5. Influence of courtyards.

Traditional houses often include a courtyard as the centrepiece and a private open area. The courtyard's proportions of length, width, and height shade certain floor sections even during the summer's hottest part of the day [10]. Common courtyards are designed with various trees and flowers to increase ventilation and enhance comfort by altering the buildings' environment. Courtyards enhance natural lighting, heating, cooling, and ventilation, according to research performed in Iran by Zamani et al. [11]. According to Ratti et al. [12], the courtyard layout provides more comfort than a pavilion (see Fig. 2). Baghdad's traditional courtyard houses (like the one in Fig. 3) may be found all across Iraq. In terms of functional requirements and internal thermal performance, they appear to have met the needs of their inhabitants. The traditional courtyard house is built around a central courtyard, with all rooms and spaces surrounding it.

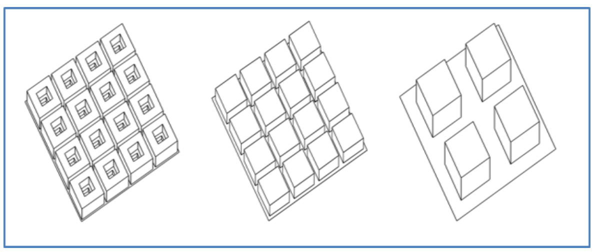

Figure 2. Traditional courtyard [12].

Figure 3. View of a traditional house courtyard in Baghdad [13].

1.1.6. Means of shading

Many people in arid areas still use the traditional "mashrabiyya." It primarily comprises wooden awnings covering large opening windows to let light and air through. It also protects the privacy of the family [14].

1.1.7. Role of the albedo

In cities, pavement and roofs make up around 60% of the surface area. These dark surfaces often absorb more than 80% of the sun's energy, converting it into heat, which has negative effects on the environment and increases energy expenses. The impacts of urban heat islands might be mitigated by replacing the pavement with more reflecting materials, improving pedestrian comfort [14]. Paving materials may heat up to 65°C in the summer, which helps to warm the air above them. More reflecting surfaces could emerge from lighter pavement materials [15]. Li [16] concluded that increasing evaporation from pavement reduces PET, temperature, and mean radiant temperature. It thus enhances thermal comfort in warm areas. Paving materials may achieve peak temperatures of 50 to 65°C during the summer, which contributes to warming the air above them. More reflecting surfaces could emerge from lighter pavement materials [15].

2. Vegetation

Vegetation and green space play a significant role in hot climate. This factor is essential in dry conditions, but designers in hot, arid climate countries did not take a decisive and efficient role in this area. It is worth noting that the requirements for sustainable urban design in hot, arid climates differ significantly from those in other climates. Notably, Soomro [17] claims that the Babylonian civilization in Iraq developed the strategy of utilizing plants in hot, dry conditions. For Sailor [18], shade trees are a frequent mitigation technique since buildings and pedestrians benefit from the evapotranspiration processes they offer while they give direct shade.

3. Microscale Numerical Modelling (ENVI-met software)

ENVI-met has primarily been modified to simulate surface plant-air dynamics in urban canyons and to forecast the climatic implications of different urban design options. The simulation time in ENVI-met is usually between 24 and 48 hours. It considers crucial modeling inputs such as beginning climatic conditions, site location, building construction, type of soil and plant, and thermal characteristics. In three dimensions, ENVI-met models interactions between radiation, temperature, heat flux, humidity, and wind flow in urban environments. Many scientists use ENVI-met to demonstrate the precision and significance of their simulation results. Lahme and Bruse [19] claim that the ENVI-met findings accurately captured the actual environment using the few numerical techniques available to gauge the size of physical processes in the real world. Numerous research has shown the reliability of utilizing ENVI-met to model the thermal performance of outdoor environments, according to Ghaffarianhoseini et al. [20]. These investigations discovered that local meteorological station measurements, observations, and simulated air temperature matched each other.

4. Study Area

Baghdad, the nation's capital, is located in the country's center at longitude 33 North and latitude 44 East, on both sides of the Tigris River. Baghdad's semiarid, subtropical, continental climate has cold winters and dry, hot summers. With nine buildings built in 1984, Haifa Street is one of Baghdad's most recognized and vibrant streets (Fig. 4) [21]. The buildings are 60m tall; the distances between them are 30 m, and in some places, 35 m; and the chosen area is 48750 m^2 As shown in Fig. 5.

Figure 4. District of Haifa Street [22].

Figure 5. Satellite Image for Haifa Street [23].

The simulated area has the following dimensions: (48750) m^2. A grid of 60 cells on the y-axis, 130 cells on the x-axis, and 20 cells on the z-axis make up the model area for Haifa Street. The dimensions of a grid cell were dy=2.5m, dx=2.5m, and dz=5m. The model was rotated at 57° to the main North direction, as shown in Fig.s 6 and 7.

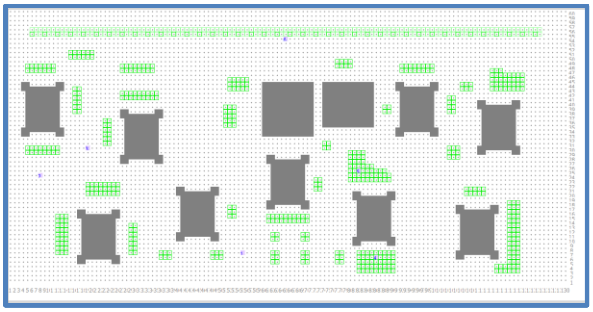

Figure 5. Haifa Street simulated by ENVI-met.

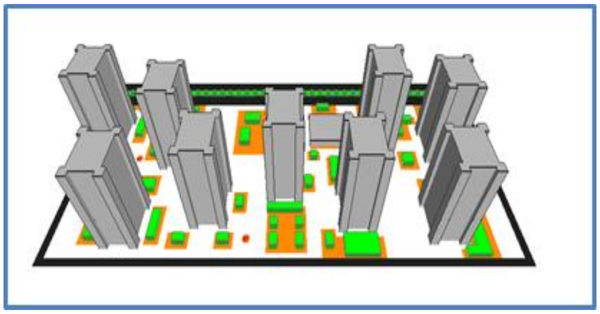

Figure 6. Perspective view of Haifa Street.

5. Criteria for the Proposal Model Design

The prior evaluation results serve as a foundation for the criteria for the chosen design. We also consider Iraq’s Ministry of Housing and Construction specifications and recommendations. We want to see if we can improve things by changing the design of the studied district. The following criteria were used to create the model design:

1. There are no more than eight stories of residential structures, and each level has a maximum height of three meters. As a result, we chose a building height of 25 meters.
2. The H/W= 1 aspect ratio determines the distance between buildings; we chose H to W=1, thus the distance between buildings is 25 m.
3. The direction is NW-SE according to the “Iraqi Housing Technical Standards” and “Codes of Practice Report” created by “Polservice” on 1982.
4. Because albedo influences thermal comfort, concrete pavement lights were chosen for the pathways and concrete pavement grey for the major roadway.
5. As illustrated in Fig. 7 shows, providing shade is crucial to improving thermal comfort, thus, we use pergolas to shield individuals from the direct impacts of solar energy.
6. We focus on using plants, grass, and trees to increase the effect of vegetation on ambient thermal comfort. The proposed model is shown in Fig. 8 and contains buildings, pergolas, and vegetation.

Figure 7. The shaded passageway for pedestrians.

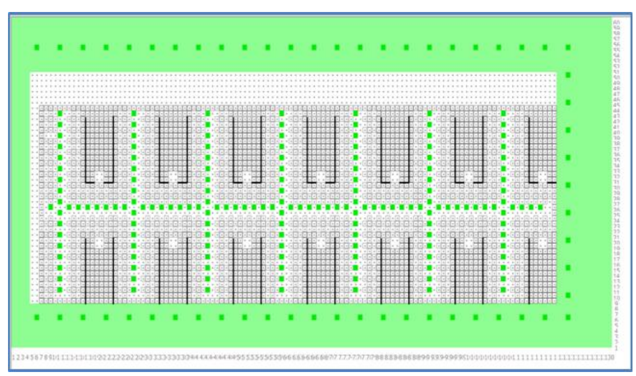

Figure 8. The proposed model (PM).

6. Indicators of thermal comfort

A psychological condition in which pleasure is thermal comfort is human thermal comfort. The most crucial element affecting a person's thermal comfort in an urban outdoor setting is the mean radiative temperature (TMRT)[21, 24]. The quantity of long- and short-wave radiation flux absorbed through the human's body, impacting its thermal comfort and energy balance, is another definition of TMRT [25]. The Predicted Mean Vote (PMV) index is a gauge of external thermal comfort depending on heat balance and temperature perception parameters [26]. It is crucial to note that physiologically relevant thermal indices produced from human energy balance models, like the Predicted Mean Vote, are considered to be most strongly influenced by the mean radiant temperature (PMV).

7. Summer day evaluation

The Iraqi Meteorological Organization and Seismology provided the meteorological information necessary to start the simulation. The relative humidity and air temperature of a usual summer day in Baghdad on June 22, 2010, are reflected in the microclimate parameters. 2.4 m/s and 315 degrees wind speed and direction were the beginning conditions. The air temperature and relative humidity baseline is 30°C at 6 am and 40°C at 7 evenings. The humidity levels maximum at 8 a.m. and dropped to 25% at 2 p.m. The whole simulation duration was 24 hours. On a typical summer day, we compare the results of the air temperature, wind speed, mean radiant temperature, and PMV between Haifa Street and the recommended model. The percentages of the air temperature for Haifa Street during noon and the (PM).

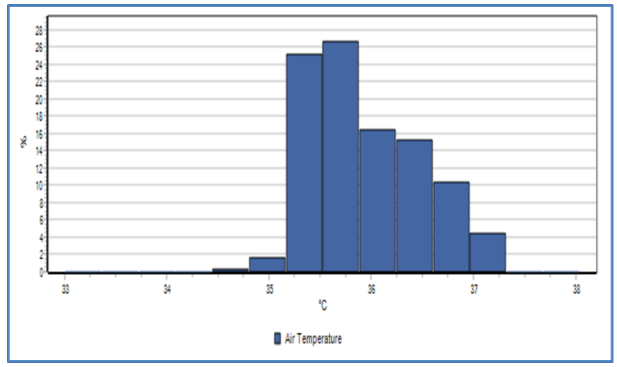

Figure 9. The Haifa area's percentage air temperature value.

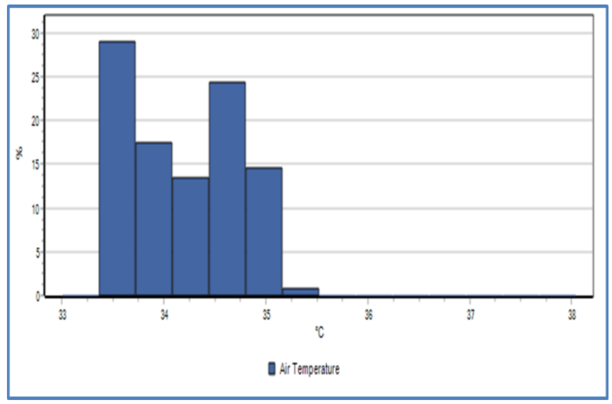

Figure 10. the PM's average air temperature.

The revised design allowed the temperature to drop below 35°C. According to the results of the mean radiant temperature shown in Figs. 11 and 12, the (PM) model fell by 10.5°C in a percentage of 90%.

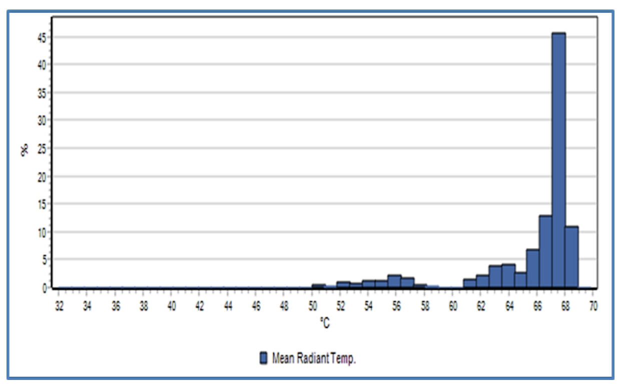

Figure 11. The percentage value of Tmrt for Haifa.

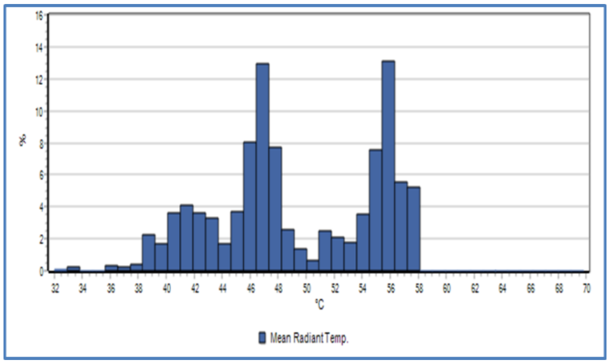

Figure 12. The percentage value of Tmrt for the (PM).

As shown in Figs. 13 and 14, the Haifa Street district is distinguished by a PMV of more than 4 in more than 99 percent of the instances. In comparison, only around 32 percent of its surface and 68 percent of its area are described by a PMV between 2.5 and 4. On a typical summer day, the new design concept offers more favorable thermal conditions than Haifa Street.

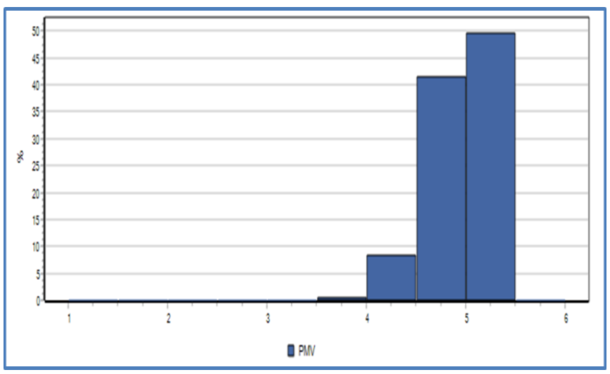

Figure 13. The percentage value of PMV for Haifa.

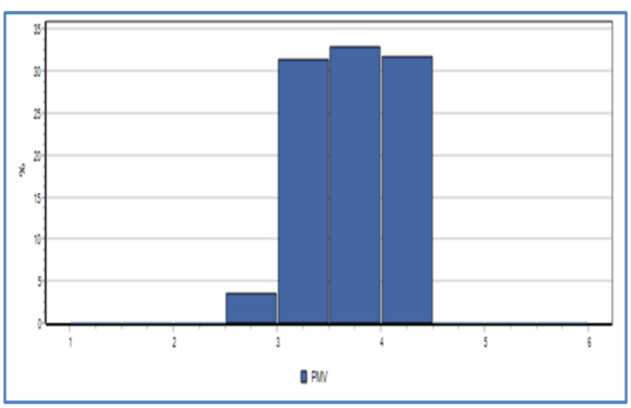

Figure 14. The percentage value of PMV the (PM).

8. Conclusion

Due to the high levels of long- and short-wave radiation radiated by the nearby surfaces, Haifa Street has the highest mean radian temperatures (Tmrt). Tmrt is lower in the suggested model because plants and pergolas cast more shadows. The new layout relies heavily on plants and parasols to provide enough shade, lowering air temperature and movement. We conclude that greenery and pergolas have the most impact under ordinary daytime circumstances. In order to moderate the effects of air temperatures, Tmrt, and PMV, shade from plants and pergolas is essential. The Tmrt, air temperature, and PMV for the PM significantly decrease on an ordinary day, according to the results.

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Conflict of interest

The author confirms that the publication of this article causes no conflict of interest.

Author Contribution Statement

All authors proposed the research problem, developed the model of the research, and computed the results. They also discussed the findings and contributed to the final manuscript.

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