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# THE IMPACT OF VARIOUS PATTERNS OF RESIDENTIAL BUILDING DESIGN TO CONFRONT THE CHALLENGES IN CLIMATE CHANGES IN AN ARID ENVIRONMENT, BAGHDAD CITY-CASE STUDY

SUAAD RIDHA

College of Engineering, Mustansiriyah University, Baghdad-Iraq
*Corresponding Author: dr.suaadalzubaydi@uomustansiriyah.edu.iq

## Abstract

Attaining sustainability in the cities is one of the priority goals currently being pursued by researchers , especially in a hot and dry climate. Studies on enhancing human thermal comfort and developing sustainability are insufficient and strictly restricted in the arid local weather, the causes could also be attributed to the two lack of preparedness for healthy environments or the desire to raise environmental understanding and want to keep up with technical developments in urban architecture. This work is an investigation study that focuses on possible mitigation strategies to ensure how we could improve thermal comfort at the pedestrian level conducted in an urban area in Baghdad city, characterized by an arid climate with very high temperatures in the summer season reaching 50°C. This study aims to suggest various building design patterns and investigate their effects on improving pedestrian thermal comfort. The study demonstrates a proposal area design in an arid climate based on structural and implementation criteria to enhance pedestrian thermal comfort requirements and how urban considerations such as sky view factor, building orientation, vegetation and shadings influence pedestrian thermal comfort. The evaluation was carried out on the hottest day of the summer, the mean radiant temperature and air temperature distributions were investigated using ENVI-met software. The Predicted Mean Vote (PMV) is used to measure thermal comfort. The findings show that a 5°C decrease in air temperature in the courtyards, as well as the passage of pedestrians, results in PMV index values ranging from 5 to 6.5. The outcomes confirmed that the elements regarded in this find out about play an essential role in the sustainable cities' strategy in arid local climates, like aspect ratio, vegetation , shading patterns, the design of canyons , the shape of buildings design.

Keywords: Arid climate, Building orientation, ENVI-met, Mean radiant temperature, Predicted mean vote, Shadings, Sky view factor, Vegetation.

## 1. Introduction

Recently, developing cities in a hot, arid environment and ensuring an acceptable degree of outdoor thermal comfort is one of the planners' most important challenges. These challenges include how to acquire the right environment for pedestrians during the day under the blazing sun, particularly in countries with a significant increase in summer temperatures and for several months, such as Iraq. Owing to the proliferation of population development in metropolitan areas, thermal comfort issues have come to attention in considering the impact of urban heat island (UHI) in hot and dry environments.

Bagdad has been selected as a case study because it has a multitude of characteristics in city forms; it is also one of the best examples of cities in hot-arid climates. The patterns of Baghdad city include the typical long-urban region that was established mainly in the 17th century; the areas that grew predominantly in the suburbs in the middle of the 20th century; and the areas that were mainly built in the last quarter of the 20th century and which are situated in the periphery of cities. Researchers in hot arid environments have found that several experiments have concentrated on understanding the role of city features in telling the UHI influence.

In addition to environmental factors such as air temperature, humidity and speed, the mean radiant temperature of TMRT plays a major role in evaluating the outdoor thermal comfort of the human body as it is responsible for various forms of radiation. These types consist of short-wave direct and diffuse radiation and reflected radiation from adjacent horizontal and vertical surfaces.

## 2. Literature Review

### 2.1. Geometric description of the urban fabric

It is essential to explain the fabric of buildings and open spaces in terms of quantifiable measures that reveal its density or other properties that influence the micro-climate. One of the most extensively used models for creating such a description is the urban canyon [1]. The geometry of the urban canyon may be described by three representations, as shown in Fig. 1.

i. Aspect ratio (H/W): specifies the sectional proportions of the urban canyon, which represents the ratio between the average height of adjacent elements (such as building facades) and the average width of the space (the wall -the to-wall distance across the street).
ii. Street orientation : the canyon axis orientation (θ) represents the direction of the elongated space, measured (in degree) as the angle between a line running north-south and the main axis running the length of the street or other linear space, measured in a clockwise direction.
iii. The Sky View Factor (SVF): is closely related to its aspect (H/W) ratio, as it also describes the cross- sectional proportions of the canyon. SVF is the proportion of the sky dome that is (seen) by a surface; either from a particular point on the surface or integrated over its entire area.

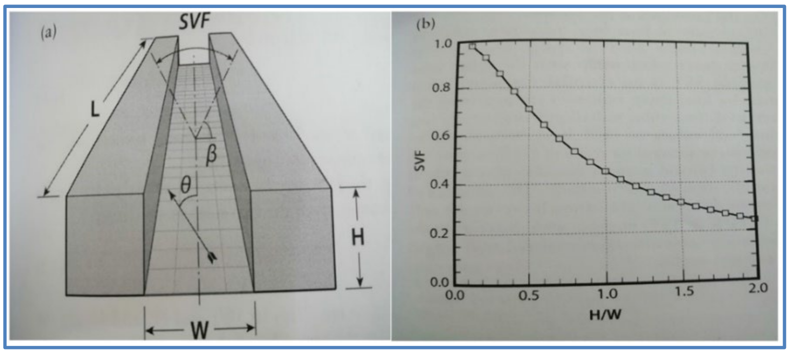



**Fig. 1. Schematic view of a symmetrical urban canyon and its geometric descriptors (a) and sky view factor (SVF) as a function of canyon aspect ratio (H/W) [1].**

## 2.2. Design requirements in an arid climate

Urban geometry factors deal with the parameters design of an urban area which involves the height of buildings and correlation with the spacing between the corresponding buildings which represent aspect ratio. Some designers prefer to design the urban area with symmetrical street aspect ratio, and another designed with an asymmetrical street aspect ratio which depends on the specification of the urban area and the commitment by the characteristics of design buildings when the implementation of the project. A research work indicated that design selections like roads, pathways, shading systems, materials, landscape design, buildings height, have a major effect on the thermal safety of the pedestrian, and subsequently on the urban climate [2]. A study suggested the parameters as shown in Fig. 2 which may be modified by the impact of urban activity, thereby improving the conditions for outdoor thermal comfort [3].

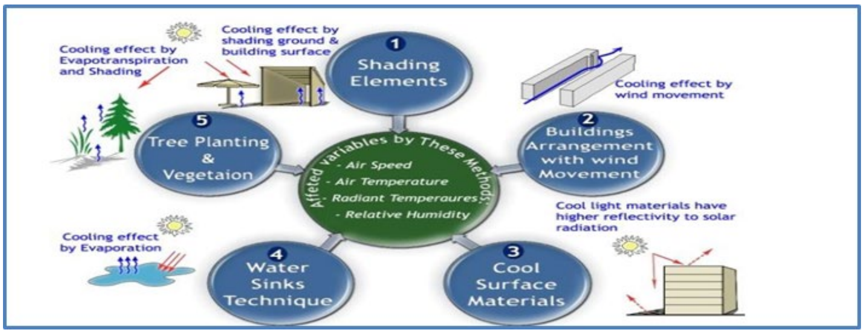



**Fig. 2. The impact of cooling for the urban interventions [3].**

The highlighted effect of the aspect ratio leads us to discuss the role of the sky view factor extensively because they correlate together with the urban geometry parameters. Sky view factor affected by the presence of vegetation and spacing among buildings a fundamental role which plays in increasing or decreasing the openings of the sky that influence the amount of sunlight that reaches the surfaces of buildings and ground, see Fig. 3.

**Fig. 3. Illustration of sky view factor: open and closed spaces [4].**

A simulation approach was taken to study the influence of the sky view factor at the daytime for differences high-rise and high-density buildings in Hong Kong [5]. Three configurations were proposed for an urban area by considering both the effect of sky view factor and building height Fig. 4.

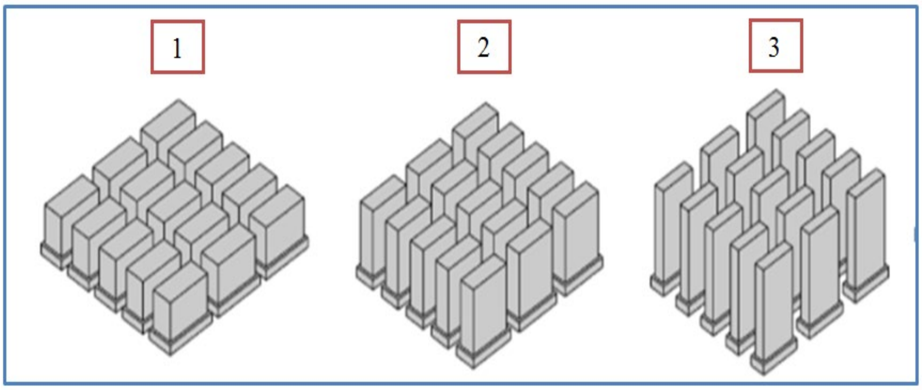



**Fig. 4. Characteristics of building configurations for an urban area [5].**

Table 1 explains the characteristics and recommendations of building configurations of this study for the three shapes adopted for the researcher [5]. The study confirmed that the SVF analysis is significant and useful in conducting studies on high-rise and high-density building cities.

**Table 1. Characteristics and recommendations of building configurations [5].**

| Configuration | Characteristics | Effect | Recommended |
|---|---|---|---|
| 1 | Small tower | Inordinate height | Un aesthetic appearance |
| 2 | Medial podium with medial tower | Large SVF with reasonable height | low thermal load and aesthetic form |
| 3 | large tower | Small SVF | High thermal load |

Street orientation is the most significant factors that highlight its importance in the effect of the amount of solar radiation on pedestrian walkways. A study concluded that narrow pedestrian walkways play an essential role in enhancing thermal comfort, because of these passages give shadings at diurnal and lessen the quantity of heat absorbed by the surfaces [6]. The Housing Technical Standards and Codes of Practice Report of Iraq recommends the orientation of structures in hot-dry zone prefers within 350 south-easts is advisable, also buildings should be elongated on the east-west axis. A research work [7] emphasized the same important remark as shown in Fig. 5 that was referred by The Housing Technical Standards about building orientation in hot-dry regions [8].

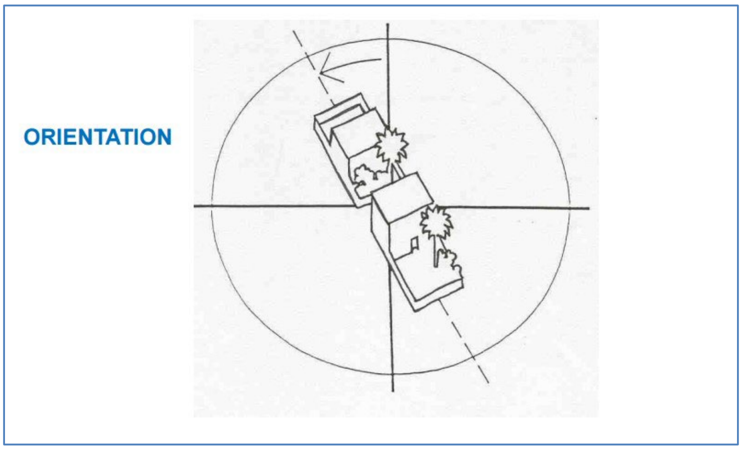



**Fig. 5. Building orientation in hot-dry regions [7].**

Using some physical elements like pergolas, cantilever lintel and arches, courtyards and the patios in some buildings, and colonnades (arcades) consider as protection methods in hot climates, which providing shading by decreasing the effect of solar radiation thus enhances the human thermal comfort. shade considers as a prerequisite for cooling outdoor spaces.

Two reasons for the importance of shading shown below [9] :

- Protection from solar radiation which has larger physiological effects in reducing heat stress than the effects of reducing the air temperature without providing shade in outdoor spaces.
- Shading does not involve any expenditure of energy or water for irrigation, as another system for reducing air temperatures in an outside area.

Design structures symmetrically have allowed imparting shading for the passageway, the symmetrical distribution for the structures make contributions for enhancing outdoor thermal comfort in arid zones [10]. The amount of the shaded area of the courtyard depends on the proportion of its three dimensions and the orientation [11]. A study indicated that human beings in courtyards might also expose to the impact of the direct and indirect of solar irradiation Albedo represents the fraction of sunlight reflected by the surfaces; the designer must be interested considerably in selected albedo for the surfaces of buildings and grounds [12].

### 2.3. Thermal comfort indices

Human thermal comfort can be described as the condition of the mind in which satisfaction is thermal comfort. The most important factor affecting human thermal comfort in an outdoor urban area is Mean Radiant Temperature (TMRT) [13]. Furthermore, TMRT is described as the amount of both short-wave and long-wave radiation fluxes absorbed by the human body, which affects its energy balance and human thermal comfort [14]. The Predicted Mean Vote (PMV) regards the index to determine outdoor thermal comfort, which is dependent on heat balance and perceived temperature parameters [15]. It is worth noting that the mean radiant temperature is thought to have the greatest effect on physiologically important thermal indices such as the Predicted Mean Vote (PMV), which are obtained from human energy balance models.

### 2.4. Vegetation and enhancing thermal comfort

Regarding vegetation, the designer needs great attention to the importance of vegetation at the terms of providing the appropriate shade and the role of afforestation in increasing the affectivity of thermal comfort for humans. The most common and environment-friendly strategies which are utilized to improve the thermal sensation in hot, dry climates are planting trees and vegetation. These methods play important roles in moderation amount of solar radiation that absorbs by the surfaces.

Vegetation plays a vital role that effect in improving thermal comfort. Vegetation contributes to enhancing human thermal comfort even when its impact on air temperature is negligible. The despite fact that many researchers focus on reducing air temperature, but it’s the radiant exchange that is often the dominant factor which affecting thermal comfort in a hot, arid climate. Vegetation contributes to improving outdoor thermal comfort not only by directly shading a person but also by reducing long-wave emission from the surfaces and by restricting the amount of solar radiation reflected from them [16].

According to an investigation study, the maximum benefit can be acquired from presence vegetation in a hot climate is the shading feature that could lessen the intense solar radiation due to the saving of radiation by the surfaces [17]. The shade of the trees represents a typical mitigation strategy for pedestrians especially in the identical conditions for hot hours of the daytime. As a result, the studies revealed that outdoor thermal comfort is highly influenced by the short and long-wave radiation fluxes that accompany the human activity. In addition, vegetation, along with street orientation and aspect ratio, plays an important role in summer heat reduction techniques.

## 3. Methodology

### 3.1. Study area

Baghdad is located in the middle part of Iraq on each aspect of the Tigris River Fig. 6. It positioned on latitude 43 East and longitude 34 North. The ambience of the Baghdad city is characterised as a semi-arid, together with hot dry in the summertime, and cold winter. Baghdad location covers 4555 km$^2$.


**Fig. 6. Baghdad position according to Iraq country (www.worldatlas.com).**

## 3.2. Urban microclimate simulation

ENVI-met is a software program that can simulate climates in city environments and evaluate the influences of climate, vegetation, construction, and materials. This software program was chosen as a simulation tool due to its capabilities to imitate the microclimate of complex city construction and according to the justifiable physical basis [17, 18]. Many researchers prove the dependability of the results of ENVI-met in many applications related to the study of thermal comfort of cities. These researchers defined that the information blanketed at local meteorological areas appeared to agree with the simulation outcomes.

## 3.3. Data for the proposed design

Information that is assumed to simulate the proposed design used to be appointed utilizing the Iraqi meteorological corporation and seismology. The researcher adopted the hottest day in summer season for Baghdad city that was 12th of July in 2010 [19]. Consequently, simple forcing for relative humidity and air temperature had been utilized for one day, which illustrates that the maximum temperature used to be 50 ºC at four pm, and the minimum air temperature used to be 35 ºC at six am. For wind direction 315º and 5 m/s for wind speed.

The minimal relative humidity m was once 24%; the maximum relative humidity was once 36%. Time of the simulation work is 24 hours. The model area has been carried out with grid size $x$= 60, $y$= 60 and $z$= 30, these grids size are described in grid cells, sizes of these cells are $dx$= 3 m, $dy$=3m and $dz$=2m. The suggested model has been rotated of 50º relying on the structure's orientations and typical roads in a desert climate [20].

## 3.4. Model configuration

The researcher depended on the suggestions and findings of previous researches and studies, which were described in this work, to design the area that has been implemented in Baghdad to boost the outdoor thermal comfort for pedestrians on the hottest day of summer. It also relied on the building conditions and design criteria from the Ministry of Construction, Housing and Public Works in Iraq. The proposed design was divided into three regions. The first location (A) consists of residential houses 10 m high; these houses have been linked with parasols to protect the pedestrians as shown in Fig. 7, section (A). The height of these parasols is 4 m. the existence of the pergolas contributes to improving the active role of shading and enhancing the outdoor thermal comfort at the pedestrian's level at noon. The reducing of solar access from the canopy openings leads to the low absorption of the long-wave radiation from the ground surfaces. Figure 7, section (B) represents high rise buildings with 30 m height and a structural section with U shape. The planting was used to be positioned inside the location that represents a letter area U to enhance the ventilation and humidification within the courtyards of the buildings, which leads to an increase in air recovery in this area due to the movement of the hot air stream outside the building. According to Fig. 7, section (C), the buildings distributed symmetrically with 25 m in height and a sunshade with 5 m was created inside of the buildings to enhance the thermal sensation for the walkways around the buildings at the pedestrian level. It deserves to mention that the walls of the tall buildings were covered with one layer of glass for heat protection. The model has been rotated by 50 ° based on the position of the buildings concerning the main North direction. The orientation is based on the Technical Housing Standards and the Code of Practice of Iraq [8]. It should be noted that the model design is based on the use of pergolas in section (A) to provide ventilation and comfort sensations for pedestrians passing through the passages. Furthermore, tall buildings, such as those seen in sections (B) and (C), could improve the shading for the pedestrian walkway.

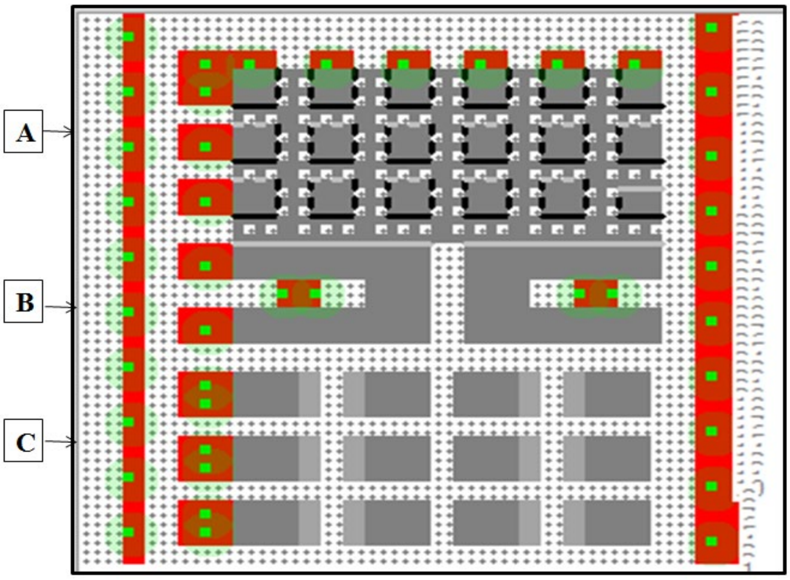
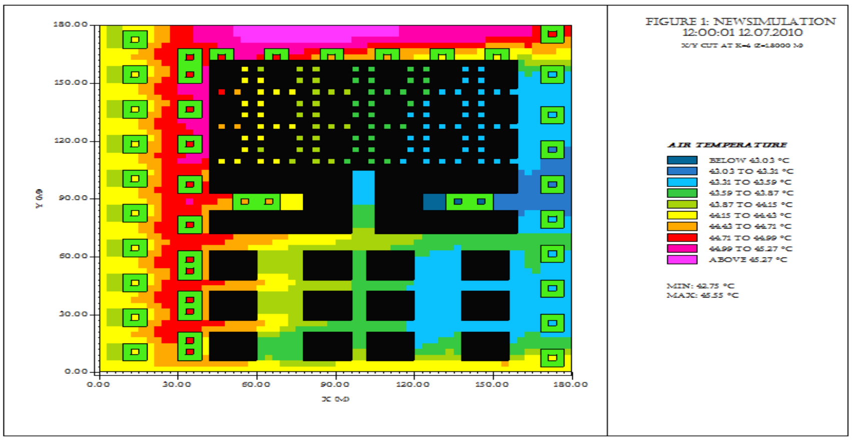



**Fig. 7. Distribution of the three patterns of buildings designed and simulated by ENVI-met.**

## 4. Results Analysis

This study is focused on mitigating the heat stress during the elongated summertime in Baghdad by a suggestion of a novel design for a resilient metropolis with various patterns design. The results of the simulation proved that the diversity of the climate variables is important in terms of wind speed, air temperature and mean radiant temperature. In relation to Figs. 8 and 9, the analysis of air temperature results highlighted that there is a lessening of 4.4 ºC in air temperature dramatically outside the construction buildings of the proposed city design. Also, there is a decreasing in air temperature in the courtyards and the passageways of pedestrians of 5 ºC. This could be attributed to the presence of the pergolas especially in section A, and the effect of shading of tall buildings of section B and C. The existence of pergolas and tall buildings play an essential role in reducing heat stress cause to minimise the solar access and lessen the quantity of energy flux absorbed by the ground surfaces and facades. The porches in section C enhancing shadings which prevent the path of the long-wave radiation between the structures, ground, and sky, and thus leads to reduced heat absorption at diurnal.



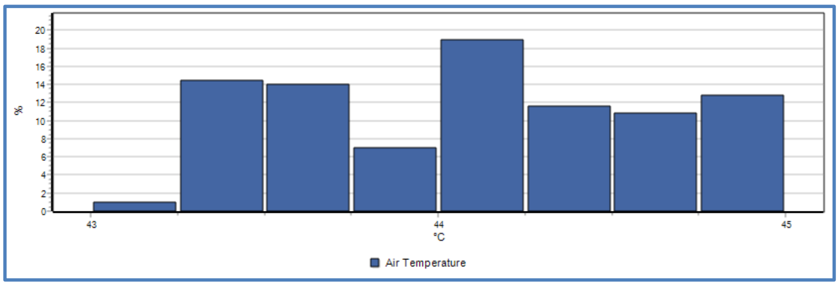




**Fig. 9. Air temperature histogram for the designed model simulated by ENVI-met.**

Regarding the mean radiant temperature, the results as shown in Figs. 10 and 11 reveal that the presence of the shade from both the tall buildings and vegetation are the most effective measure to decrease the maximum values of TMRT.

According to a research study, there is a comparative relation between the mean radiant temperature and the sky view factor during daytime [21].

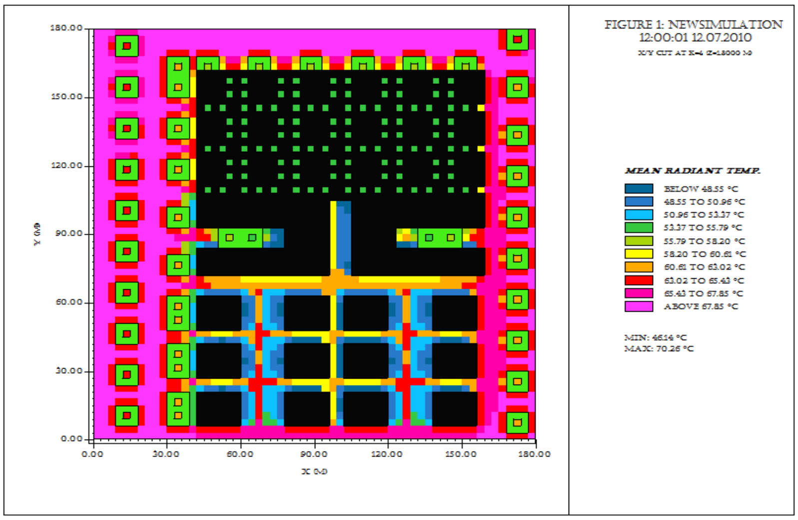



**Fig. 10. TMRT distribution for the proposed model at noon.**

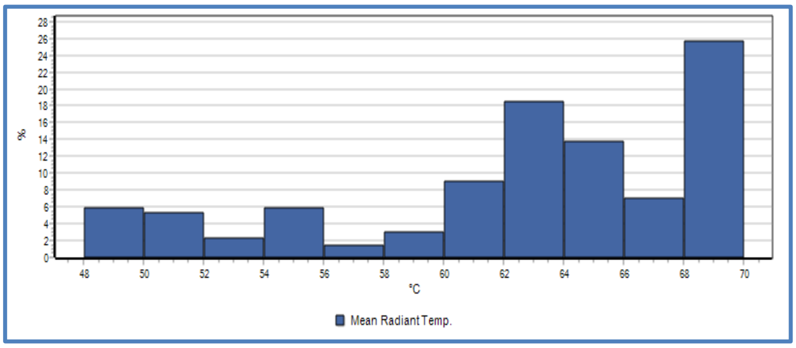



**Fig. 11. Mean temperature histogram for the designed model simulated by ENVI-met.**

Pergolas and porches reducing the values of sky view factor, as shown in Fig. 12 which conducts to a reduction in the value of TMRT. Shading reduces the direct short-wave radiation entering the buildings and ground surfaces as well as persons. Figure 13 reveals that 60% of the sky view factor values are 0.15 this means that the openings of the sky are more closely caused to the existence of vegetation and pergolas. This which enhance the shading and improve thermal sensation.

Generally, PMV values are defined by -4 Very Cool and +4 Very Hot, 0 means that thermal comfort value Neutral, as presented in Fig. 14. The application of PMV equation to the outdoor thermal requirements in summertime temperature stress conditions can effectively give values of PMV +8 and more. Mathematically, these results are considered accurate despite it encroaches the scale of the actual PMV (www.ENVI-met.com). Figure 15 represents PMV distributions for the proposed model at noon. We notice that the suggested design obtains amelioration in the thermal sensation; PMV values range (5 - 6.5). Figure 16 depicts the percentage value of PMV for the suggested design at noon.

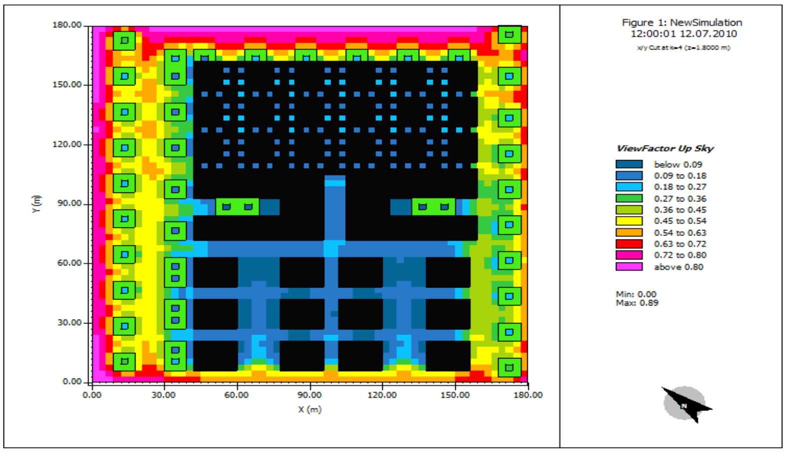



**Fig. 12. Sky View Factor distribution simulated by ENVI-met.**

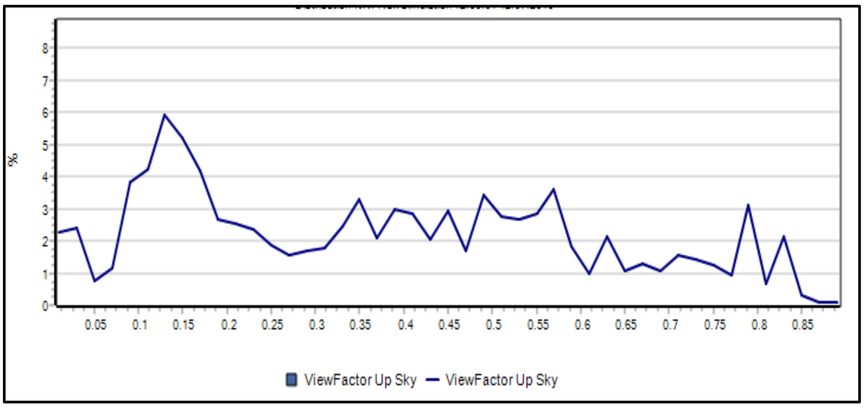



**Fig. 13. The percentage value of Sky View Factor for the proposed design at noon.**

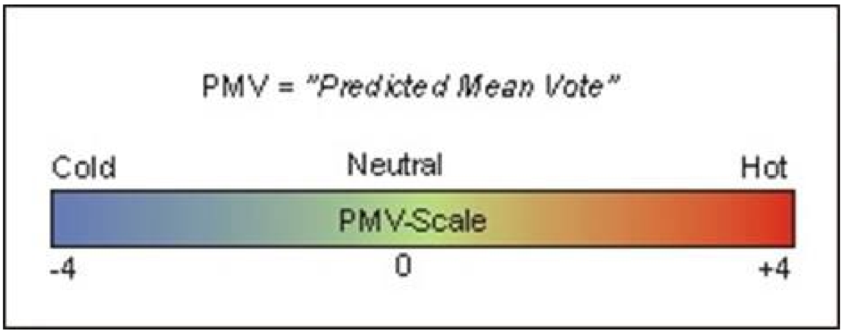



**Fig. 14. The standard scale of PMV (www.ENVI-met. com).**

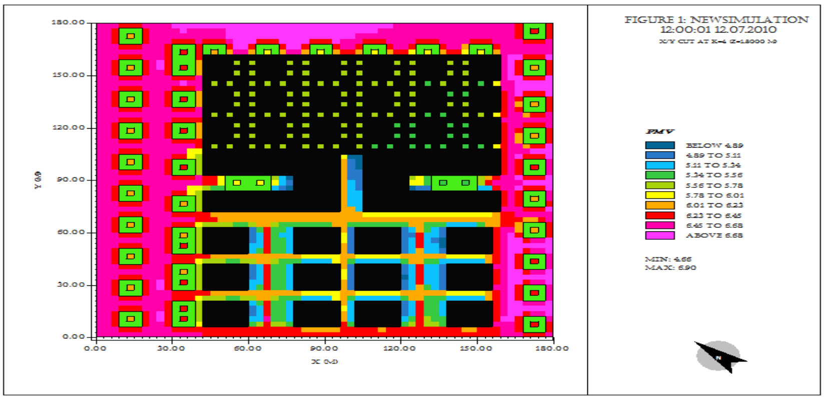



**Fig. 15. PMV distributions for the proposed model at noon.**

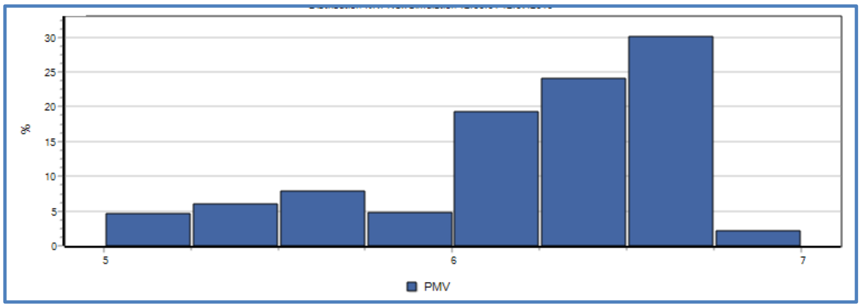



**Fig. 16. The percentage value of PMV for the suggested design at noon.**

## 5. Conclusions

The results showed a decreasing in the air temperature of about 5 ℃ in the courtyards also the passage of pedestrians. Also, we observe lower values in the mean radiant temperature between buildings and the passages way of the pedestrians than theses values on the foremost avenue and the open areas outdoor the suggested city. Notable that is the highest values of the mean radiant temperature was exhibited outside the region of urban buildings due to the high amount of the radiation reflected from the facades. We deduced that the values of mean radiant temperature can be impacted considerably by the city design, aspect ratio, and the shadings in the arid climate. These factors present an essential effect in the evaluation of bioclimatic requirements and thermal sensation. For thermal comfort index, the values of PMV have been elucidated from the results of the simulation; we notice amelioration in the thermal sensation thanks to recording moderate values of PMV. The inclusion of parasols in section (A), as well as the support for using tall buildings to provide shade in pedestrian walkways in sections (B) and (C), greatly improved pedestrian thermal comfort, which mainly led to provide adequate ventilation and decreased heat stress at noontime. The outcomes confirmed the reality that the diversity of patterns of buildings design contributes to suggest a suitable design that confronts climate change in Baghdad, specifically for the summer season. Subsequently, the results that had been obtained from this research can be held to be a guide for the designers regarding the studies of thermal requirements and urban design in an arid climate.

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