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Mohamed A. Eid
Department of Architecture, Faculty of Engineering, Assiut University

Randa M. A. Mahmoud
Department of Architecture, Faculty of Engineering, Assiut University

Amr Sayed Hassan Abdallah
Department of Architecture, Faculty of Engineering, Assiut University, dr.amrsayed@aun.edu.eg

ORIGINAL STUDY

A New Planning Proposal for Achieving Residents' Thermal Comfort in Hot Arid Climate-based on Simulation Model

Mohamed A. Eid, Randa M.A. Mahmoud, Amr S.H. Abdallah*

Department of Architecture, Faculty of Engineering, Assist University, Assiut, Egypt

Abstract

This paper aims to propose a new planning approach that achieves residents' thermal comfort inside the courtyards of residential complexes based on the improvement of the urban canyon ratio in the current residential complex in New Assiut City as a base case, including their role in boosting social interaction and improving residents' Outdoor thermal comfort (OTC) and courtyard air quality. This new planning proposal is based on the planning of old Arab cities that encourages liveability, walkability, social interaction, and sustainability. Then, improvement of urban canyon ratios for the new planning proposal was simulated and optimized using ENVI-met 5. 8cases for courtyards urban canyons with different aspect ratios, (H/W) = 0.8, 1, 1.2, 1.25, 1.5, hand 1.825, were simulated to determine the optimal case for each building height (15 m, 12 m), followed by the integration of different scenarios (trees, shading, water elements) for the optimization model. Values of Physiological Equivalent Temperature (PET), Mean Radiant Temperature (T_{mrt}), and carbon dioxide (CO_2) concentration were compared. The results concluded that buildings with deep canyons (W = 8) and building heights equal to 12 and 15, with aspect ratios 1.825 and 1.5, achieved the optimal reduction of air temperature and PET. There is a significant reduction in outdoor carbon dioxide concentration inside courtyards with a deep canyon of an aspect ratio of 1.825; and more reduction for PET with an average of 33.07 °C compared with the base case. The results of this study help planners and architects integrate the optimum canyon ratios in planning Egyptian cities in the early design stage, as a new planning approach for activating the neighborhood feature of planning residential areas and its direct impact on the social/administrative aspects.

Keywords: Deep canyon, New planning, Outdoor thermal comfort, Residential complex

1. Introduction

Residential communities established by humans were the first nucleus of cities. City areas are extended to meet the needs of their residents. In the past, the human scale was the governing factor in determining city size; by estimating walk distances. There is no doubt that the residential sector occupies the largest area of cities' land use, including buildings and internal urban spaces, by around 60%. Therefore, the development of these urban geometries helps improve outdoor thermal comfort and provides solutions to some environmental problems such as global warming. Open space design methods can be utilized to create social contact and a sense of community, especially in areas of transition (Salih and Ismail, 2017). Design and planning of open space play a significant role in directing people towards outdoor spaces (Uslu and Gökçe, 2010). The focus of human behavior is the most crucial element in the design of open spaces since inherent behavior is directly tied to the environment. The human and social interaction in open space is the main component of this space that attributes the space to their values and norms (Rahravi Poodeh and Pouriaye Vali, 2014). To achieve outdoor thermal comfort, a variety of design factors can be taken into account, such as the density of

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* Corresponding author at: Assiut, 71516, Egypt. Fax: +2088 233 2553.
E-mail address: Dr.amrsayed@aun.edu.eg (A.S.H. Abdallah).

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urban structures, the orientation of open spaces, the width of streets, the height of buildings, etc., all of them have an impact on how much sunlight and shade are received and heat transfer to residents doing different activity as well as how wind is deflected and accelerated through streets and squares. In the early design stages, studying the urban canyon ratios and urban mitigation strategies enhance and control microclimate. Thus urban canyon ratios are an important factor that affects residents' thermal comfort due to shading, air temperature and wind speed (Nikolopoulou and Steemers, 2003).

Mahmoud and colleagues (Mahmoud et al., 2021) have used ENVI-met to investigate the quality of outdoor thermal comfort using ENVI-met software for 18 hybrid and nonhybrid urban geometry scenarios at Aswan University Campus in Egypt. Thus, Physiological Equivalent Temperature (PET) was reduced by 4.2 °C for the East and West canyons and 6.8 °C for the North and South canyon orientations. Furthermore, several studies have illustrated different urban morphologies as mitigation methods in the outdoor space to improve outdoor thermal comfort. For example, Abdallah and Mahmoud (2022) have investigated the influence of six scenarios of mitigation strategies to improve outdoor thermal comfort in courtyards between residential buildings in New Assiut city, Egypt. According to the ENVI-met results, the reduction of PET was 19.1 °C in the deep canyon (H/W = 0.6), compared with 17.5 °C in the shallow canyon (H/W = 0.24) by the integration of grass, trees, and integration of semi-shading 50%, besides reducing the surface temperature by 10 K. Finally, Mahmoud and Abdallah (2022) have investigated the efficiency of nine scenarios of vegetation, shading units, and hybrid strategies for improving outdoor thermal comfort for students in the school courtyards (H/W = 0.4 and 0.7) using ENVI-met. The results illustrated that the best PET improvement was 18.6 °C, by applying a hybrid scenario between shading and trees in the deep canyon. Finally, Mahmoud and Ragab (2020) have investigated the impact of hybrid scenarios on outdoor thermal comfort and energy consumption in 2018 and the future in 2035, using ENVI-met and EnergyPlus. It was found that the best PET reduction of was obtained by applying shelters with 50% covering. Moreover, a set of passive strategies were studied to improve outdoor thermal comfort in a hot and dry climate such as Abdallah (2015), Abdallah and colleagues (Abdallah et al., 2020), and Bahgat and colleagues (Bahgat et al., 2020).

On the other hand, a set of papers studied the air quality and the distribution of air pollutants inside outdoor spaces to protect the users' health. For instance, Ke and colleagues (Ke et al., 2022) have analyzed the distribution of PM 2.5 concentration in six 3-dimensional metrics of different urban patterns and building morphologies. It was found that applying a combination pattern of different building heights and decentralization of landscapes can reduce the concentration of PM 2.5 by 40.94%. Nevertheless, several studies have clarified the significance of improving outdoor thermal comfort (OTC) in new desert cities in Egypt, which are expected to experience a large increase in population in the future Abdallah and Mahmoud, Mahmoud and Ragab (Abdallah and Mahmoud, 2022; Mahmoud and Ragab, 2020). Besides, an efficient role is played by outdoor spaces for boosting the social activities among residents in the residential complex. Most Egyptian cities are designed without taking climatic planning into consideration. In addition, there is a lack of studies that have addressed the improvement of OTC in new Egyptian desert cities, although it is widely available and considered the only future extension of the urban area in Egypt. Hence, the research aims to introduce a new planning proposal that can be applied in new cities of hot arid climates to enable the role of urban design in achieving residents' thermal comfort in an outdoor environment, reduction of carbon dioxide (CO_2) concentration, and outdoor air quality, enhancing relationships and social interaction and increasing residents' feeling of safety and security. We propose a new planning approach that achieves residents' thermal comfort inside the courtyard of residential complexes, based on improving the urban canyon ratio in an existing residential complex in New Assiut city as a base case; including their role in boosting social interaction and improving resident OTC and courtyard air quality.

So, the study aims to achieve optimized urban canyon ratios for new residential city planning proposals based on studying the urban canyon of an existing residential complex in New Assiut city as a base case for validation and calibration the model and investigate the efficiency of the new optimization model that can subsequently be applied in several Egyptian desert cities. Therefore, the novelty of this study is essentially achieving new optimized planning proposals for urban canyon ratios based on old cities concept; including their role in boosting social interaction as a concept and improving residents' OTC and courtyard air quality that can be integrated in planning new city layouts or residential complexes. This study focus on studying outdoor thermal comfort and air quality for resident in courtyards of new urban approach only to encourage liveability, walkability, social interaction, and sustainability. This model is based on emulating the planning of old Arab cities that adopt this concept.

2. Methodology

To achieve optimized urban canyon ratios for new residential compound layouts based on old Arab cities concept, a new planning proposal was simulated and optimized based on monitoring and validation of current residential complex in New Assiut City, Assiut; August 2014. The Youth Housing complex is one of the residential complexes in New Assiut city that was selected for model validation only Abdallah and colleagues (Abdallah et al., 2020); (Abdallah and Al-Saadi, 2020) with a wide canyon ratio (H/W) of 0.24, as shown in Fig. 1.

New Assiut City was selected as it represents a common pattern of complexes in the new desert cities in Egypt. These complex was built by Egyptian government in many cities in Egypt. The building of this complex was a prototype that repeated in different canyon ratios without taking into consideration residents' outdoor thermal comfort (Fig. 1a). shows the youth housing complex layout. Monitoring conducted inside the residential complex indicated thermal discomfort in the indoor and outdoor environments due to high solar radiation through the outer spaces and courtyards in different urban canyons Abdallah and Mahmoud, Abdallah (Abdallah and Mahmoud, 2022; Abdallah, 2015). The youth housing complex has two canyon ratio narrow and wide canyon ratios with a value equal 0.6 and 0.24, respectively. The study of this complex concluded thermal discomfort for outdoor environment due to the canyon ratios and the wide distance around and between the building Abdallah and Mahmoud (2022). Factors affecting these results were canyon ratios and mitigation strategies like shading, trees, grass, and water elements. The study overcome the wide ratios of canyon for outdoor courtyards and integration of different scenarios inside it. Therefore, a new planning proposal was needed to achieve thermal comfort with low-energy buildings and support social interaction; keeping on sustainability as well as confronting climate changes and urgent environmental issues. The new planning proposed has a central courtyard with the north side open to improve the wind speed, in addition to the narrow width of the courtyard to provide self-shading. The different between youth housing complex and new planning proposal related to the compact design with deep canyon ratio and mitigation of trees, grass, and shading based on the planning of old Arab cities.

Thus, the general description is shown in (Fig. 2a). Besides, eight cases of the optimization model are shown in (Fig. 2b), the first 4 cases with a building height of 15 m (ground floor and 4 residential floors), and the second 4 cases with a building height of 12 m (ground floor and 3 residential floors), while the width of the courtyard ranged from 8 m to 15 m. Also (Fig. 2c), shows the four scenarios to improve outdoor thermal comfort within the urban morphology inside the courtyard; scenario 1 of adding trees, scenario 2 of adding 50%

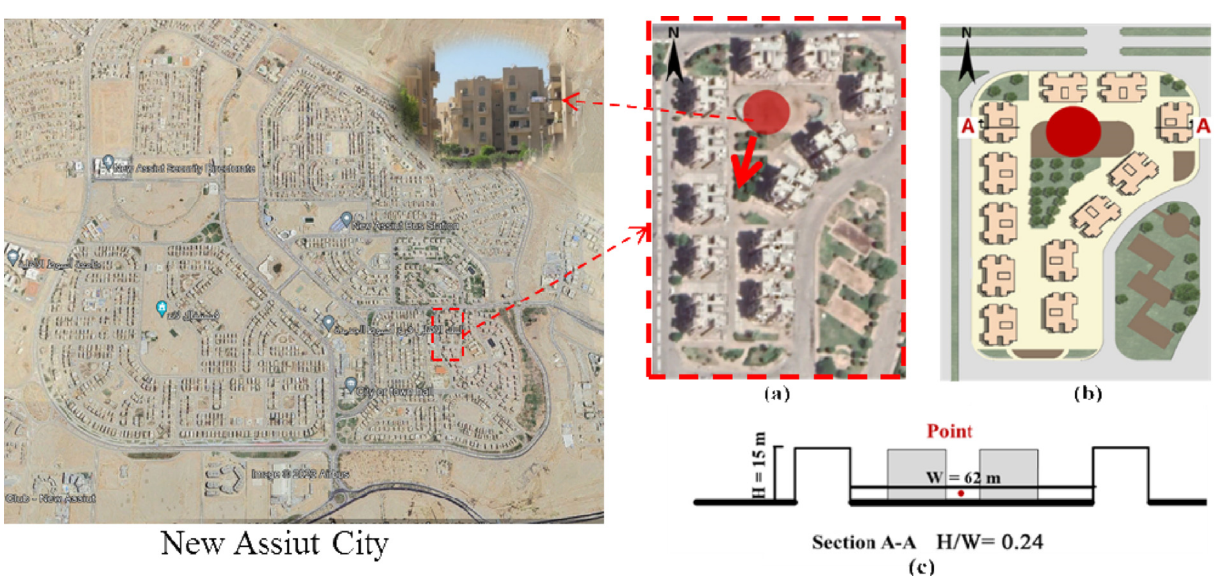


Fig. 1. The existing case of the Youth Housing Complex for model validation (author).

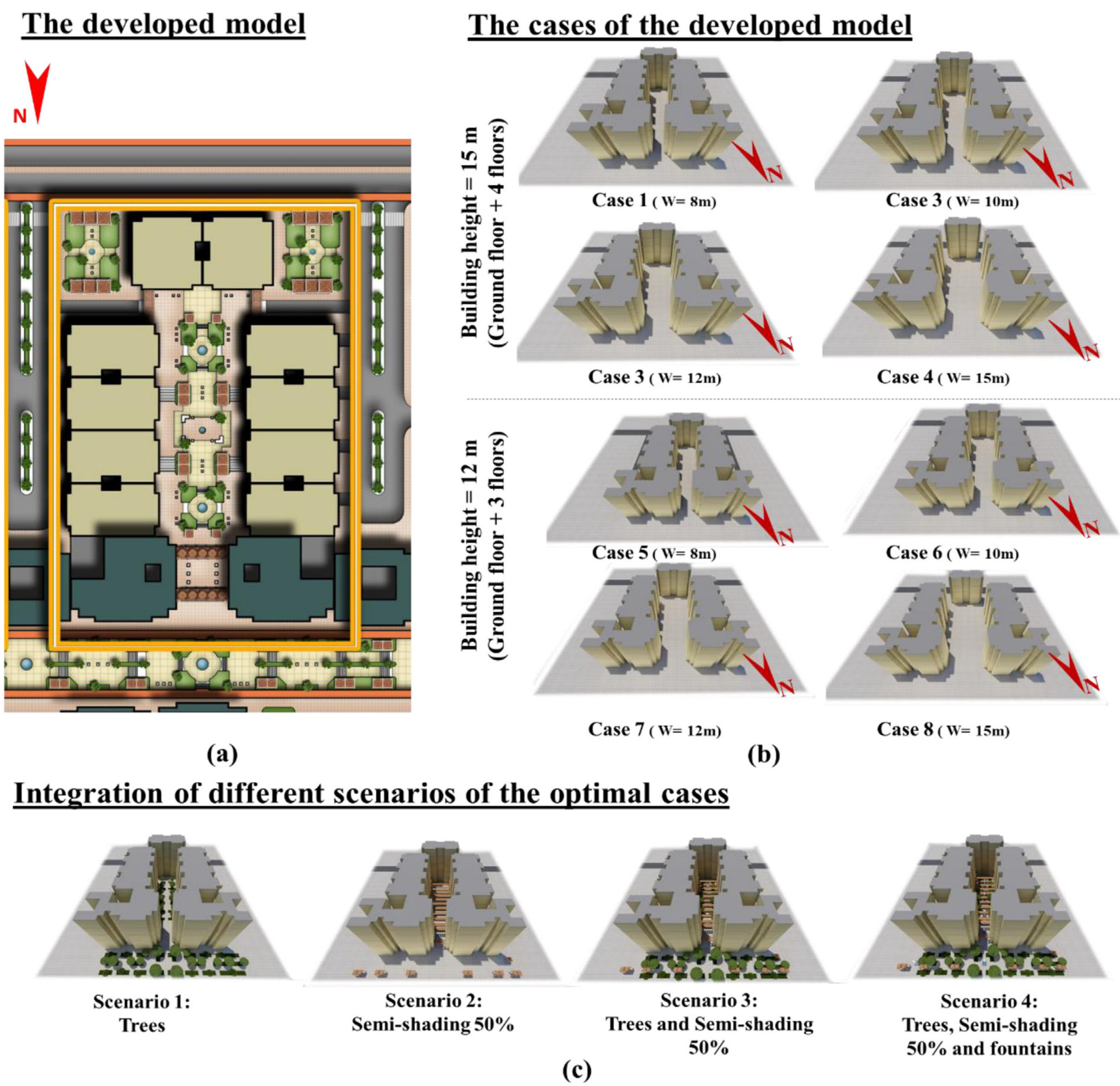


Fig. 2. The proposed model; (a) the developed model, (b) the 8 cases of the developed model, and (c) the 4 different scenarios of the optimal cases (author from ENVI-met).

semi-shading, scenario 3 of adding trees and 50% semi-shading, and scenario 4 adding trees, 50% semi-shading and fountains. To simulate the OTC, ENVI-met v 5.0.0 was used to model the optimization model and to predict its thermal performance between 8:00 and 20:00. This study focus on studding courtyard aspect ratio in urban complex and then integration different scenarios (trees and shading) only due to its effectiveness in improvement resident outdoor thermal comfort Abdallah and Mahmoud (2022) and easily to apply for the new proposal in the predesign stage. ENVI-met software is widely used in the field of urban microclimate research because of its high simulation accuracy Chen and colleagues, Zhang and colleagues (Chen et al., 2021a; Srivanit and Hokao, 2013; Zhang et al., 2022). According to the fundamental principles of thermal dynamics and fluid dynamics, ENVI-met employs predictive modelling Marshall-Ponting (2008). The software can model building physics, air ventilation between and around structures, the effects of landscaping and softscaping, as well as the bioclimatology of the local climate. It can evaluate mass and heat transfers to other surfaces as well as calculate heat exchange activities at ground surface and building walls. The ENVI-met model has been used over 150 nations over the past 20 years in over 5000 simulations (Taleb and Abumoeilak, 2021). The

Bio-Met procedure uses atmospheric (output) data to create heat indices, and the LEONARDO unit outputs show the whole output produced by ENVI-met (Fig. 3).

Optimization for the courtyard within the building complex which is considered the main place for residents to gather and practice social activities such as playing with children and meeting friends, the study focused on the courtyard more than any other outdoor space, such as the narrow spaces between buildings. Hence, the description of the eight cases of the optimization model and the four developed scenarios are shown in Fig. 4.

It is can be observed that the optimization model relied on gathering a smaller number of residential buildings and creating an inner courtyard among them to provide privacy and increase security. The proposed area for the model is 8000 m^2. The concept of the optimization model is based on creating a semi-enclosed courtyard from three sides while keeping the north side open to improve wind speed inside the courtyard. In addition, the courtyard morphology is enhanced by the vegetation strategy, the shading strategy, and water fountains.

Therefore, the OTC grades will be determined based on the thermal comfort classifications.

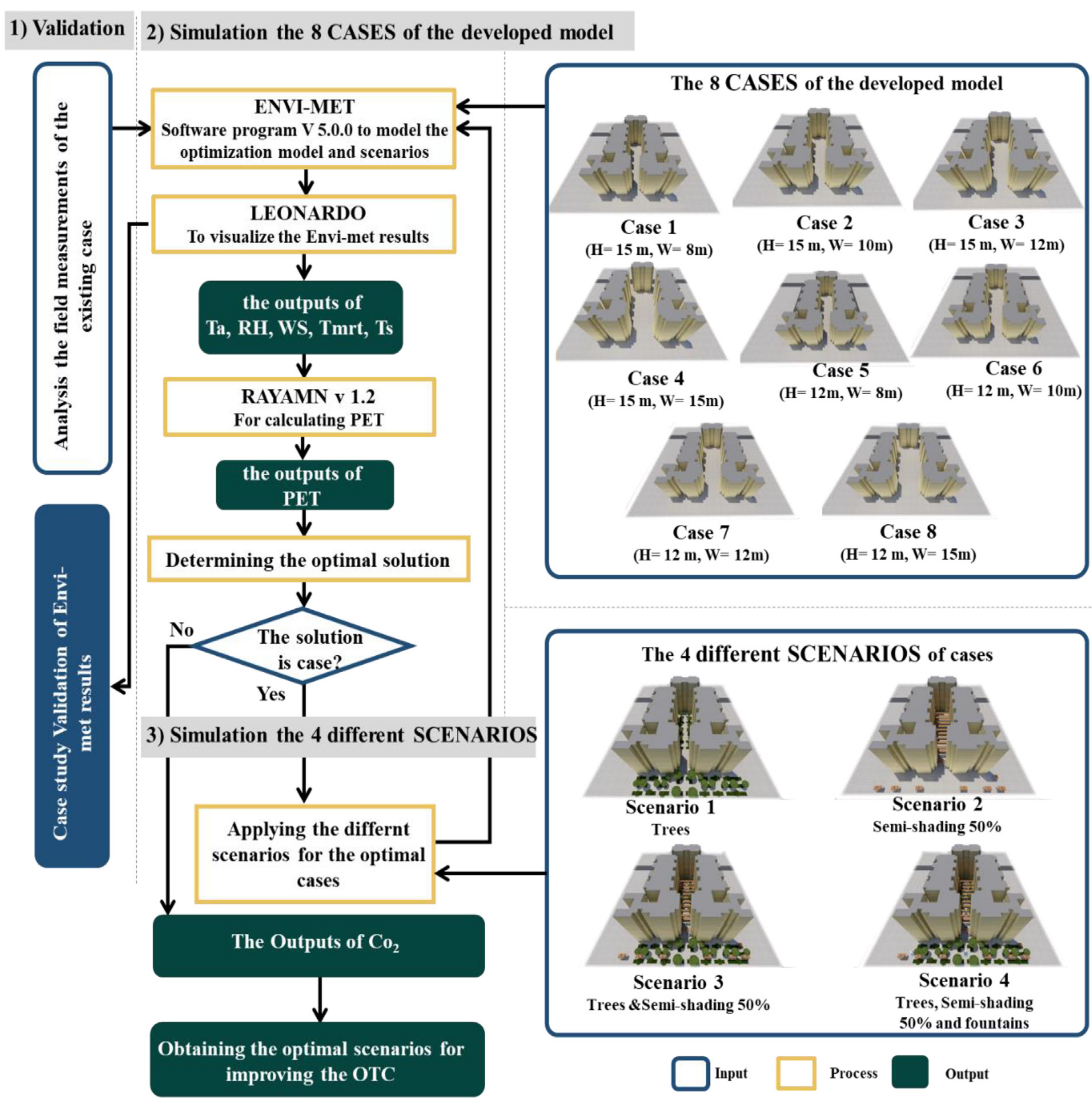
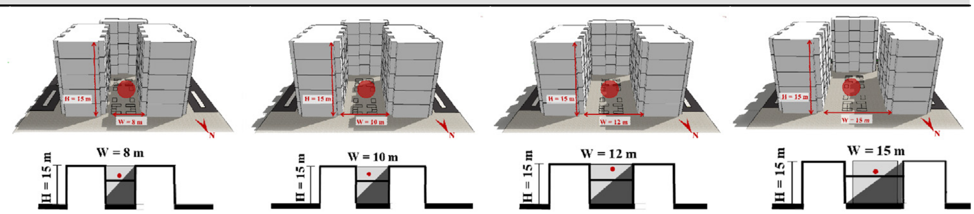


Fig. 3. The proposed methodology for the new planning layout proposed (author).

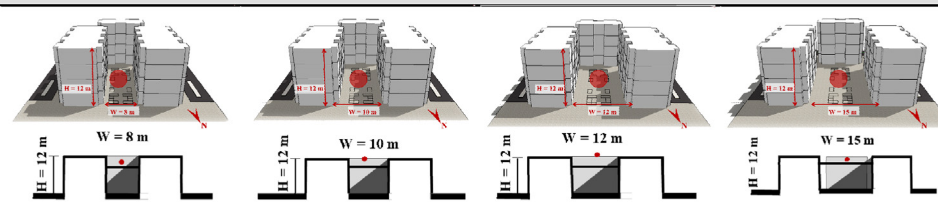
The 8 cases of the developed model

	Case 1	Case 2	Case 3	Case 4



	Case 1	Case 2	Case 3	Case 4
Building height (H):	15 m	15 m	15 m	15 m
Courtyrad width (W):	8 m	10 m	12 m	15 m
H/W:	1.825	1.5	1.25	1.0

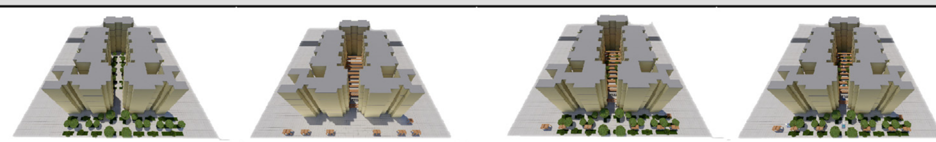
	Case 5	Case 6	Case 7	Case 8



	Case 5	Case 6	Case 7	Case 8
Building height (H):	12 m	12 m	12 m	12 m
Courtyrad width (W):	8 m	10 m	12 m	15 m
H/W:	1.5	1.2	1.0	0.8

The 4 different scenarios of the optimal cases

		Scenario 1: Trees	Scenario 2: semi-shading 50%	Scenario 3: trees & semi-shading 50%	Scenario 3: trees, semi-shading 50% & fountains



		Scenario 1: Trees	Scenario 2: semi-shading 50%	Scenario 3: trees & semi-shading 50%	Scenario 3: trees, semi-shading 50% & fountains
Green area and trees:	Type	Ficus	-	Ficus	Ficus
	Area	570 m^2	-	570 m^2	570 m^2
	Height	3 m	-	3 m	3 m
	Width	3 m	-	3 m	3 m
	Albedo	0.3	-	0.3	0.3
Shading:	Type	-	Yellow wood	Yellow wood	Yellow wood
	Area	-	240 m^2	240 m^2	240 m^2
	Albedo	-	0.15	0.15	0.15
Water:	Type	-	-	-	Water fountain
	Area	-	-	-	52 m^2
	Albedo	-	-	-	0.5

The common properties of the landscape		The common properties of the buildings	
Streets width:	8 m	Area of study:	8000 m^2
Street type:	Asphalt road	Buildings' Pattern:	Compact pattern with courtyard
Street Albedo:	0.2	Building width:	20 m
Sidewalk material:	Yellow brick road	Building length:	22 : 40 m
Sidewalk Albedo:	0.5	Façade Material:	Beige painted
Soil material:	Sandy soil		0.7
Soil Albedo:	0.35		
Green area:	none		

Fig. 4. Description of the 8 cases and the 4 scenarios of the developed model (author from ENVI-met).

Moreover, the methodology consists of three stages:

(1) Validation of the ENVI-met model by comparing its results with the field measurements conducted in 2014.
(2) Simulation of the optimization model and the 8 cases using ENVI-met to determine the optimal case for each building height (15 m, 12 m) and then, integration of different scenarios for the optimization model:
   (a) ENVI-met for modelling, thermal simulation, and CO_2 concentration.
   (b) LEONARDO tool for visualization of the results of Ta, RH, wind Speed, T_{mrt}, and CO_2, in addition to exporting Ts and T_{mrt} maps.
   (c) Rayman tool for calculating PET index.
(3) Simulation of the 4 developed scenarios for the optimal case of each building height to find the improvement of the OTC and air quality (CO_2 concentration).

2.1. Building description for validation

The Youth Housing complex in New Assiut City is the existing case study; the model of calibration to validate the model and the proposed new planning. It represents the most common prototype for low-income housing made by the Egyptian government. New Assiut City is located in the southern area of Egypt, on the eastern side of Assiut City and the Nile River.

The latitude of New Assiut city is 27°3′N and the longitude is 30°15′E. As shown in Table 1, the complex occupies an area of 17 250 m^2 and consists of 12 residential buildings, all 15 m high, surrounding a courtyard with a wide canyon ratio (H/W) of 0.24. In addition, the central courtyard is intended for social activities while preventing any through traffic.

Table 1. The characteristics of the existing area for ENVI-met validation (Abdallah and Mahmoud, 2022).

Building properties		Landscape properties	
Area of the existing case	17 250 m^2	Street width	10 m
Building width	20 m	Street material	Asphalt
Building length	15 m	Sidewalk width	4 m: 8 m
Building Height	15 m	Sidewalk material	Yellow brick
Courtyard width	62 m	Soil material	loamy
Aspect ratio (H/W)	0.24	Green area	2400 m^2
Façade material	Yellow painted	Tree type	Ficus Nitida trees

2.2. Description of a new planning proposal for enhancing thermal comfort, social interaction, and sustainability

Creating liveable, sustainable, safe, and healthy cities has become a universal goal. To achieve this goal, the human dimension must be considered, and the city must be prepared for pedestrians. One of the major dimensions to be considered in this regard is the circulation pattern of a city, and how to encourage residents to walk – through various factors combined with the concept of walkability. The planning proposal is an attempt to formulate ideas and theories related to criteria of sustainability; shape and equip spaces for social interaction, achieve the concepts of hierarchical and functional progression of activities, spaces, and circulation within residential communities; enhance the feeling of safety and security through the so-called defensive spaces, separating vehicular traffic from that of pedestrians and setting some circulation paths for pedestrians and bikers; and prepare spaces in general – at their planning and functional levels – for the purposes they were designed for with high thermal comfort. Fig. 5 shows the design criteria for open spaces with relation to liveability, social interaction, and thermal comfort. This proposal focuses on forming architectural groups to be the nucleus of the entire community. These groups include a number of buildings (medium-rise buildings) that contributes to enhancing communication and social ties among residents with thermal comfort and good air quality as shown in (Fig. 2a).

2.3. Residential communities and human dimensions

Fig. 6 shows the general features of the planning proposal. The group is linked to a main pedestrian/bicycle path that combines the group with other similar groups. The path is overlooked by a number of high-rises and mixed-use buildings; the ground floor accommodates the daily services of citizens. From the other side, the group is connected to a dead-end vehicular road, containing vehicle entrances under the residential buildings. Repeating the groups over the secondary pedestrian/vehicular paths, they form a larger group that overlooks a main axis and, thus, the nucleus of a residential district in a city (Fig. 6b). shows how architectural groups are assembled along the main pedestrian path. The new planning proposal consists of network planning (one network for pedestrian and vehicular use), two separate networks; one for pedestrians and the other for vehicles; and a vehicular

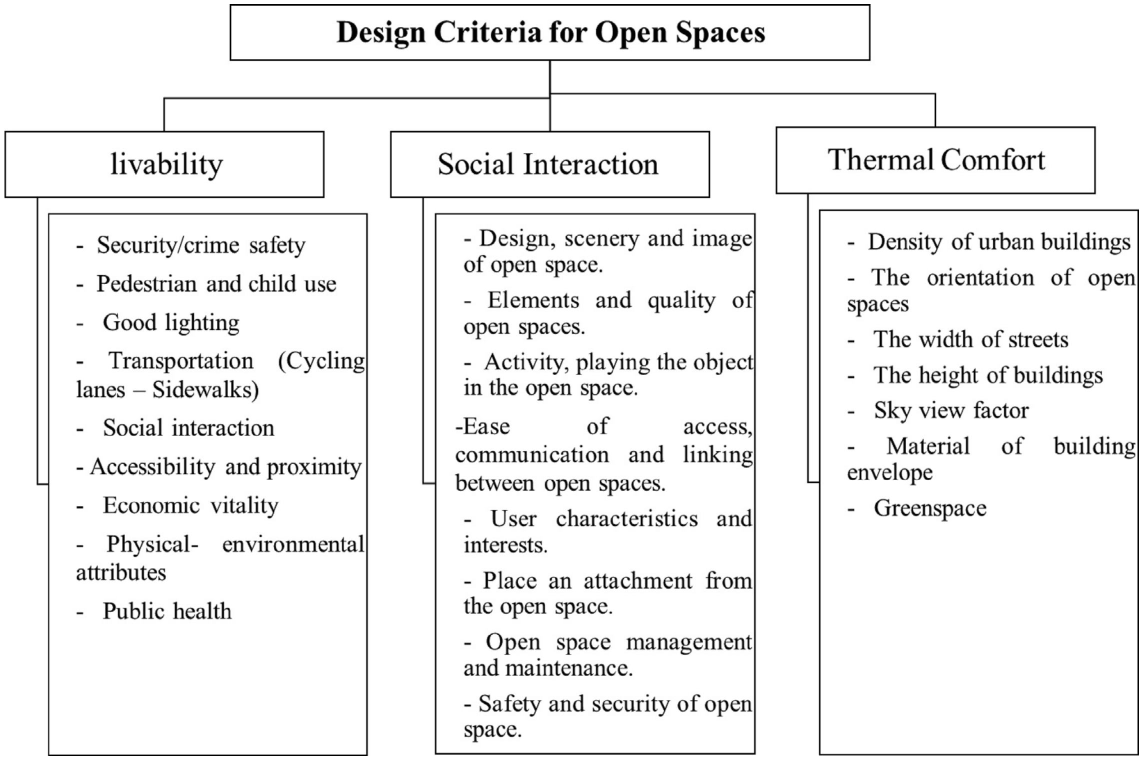


Fig. 5. The design criteria for open spaces with relation to livability, social interaction, and thermal comfort (Salih and Ismail, 2017).

network feeding a pedestrian yard network, and Plots – green areas – pedestrian corridors/yards – public road. The role of a new planning proposal helps achieve the following thematic criteria.

(1) Separating pedestrians from vehicular traffic and raising the efficiency of pedestrians' and bikers' paths.
(2) Easy realization of different elements/components of the urban area.
(3) Good formulation of the hierarchical progression of activities, spaces, and roads.
(4) Achieving sustainability for these architectural communities.
(5) Raising the quality of life and vividness of the urban spaces.

The planning proposal in its entirety emulates the planning of old Arab cities whose activities, spaces, and paths progressed very well.

2.4. Numerical simulation and validation by ENVI-Met

The characteristics of the existing case in Table 1 were utilized as the main input for modelling the case study in ENVI-met software v 5.0.0. Then, the results of the simulation model were compared with the measurement results. The field measurements of Ta and RH in the specific point have been recorded and used to validate the ENVI-met model. Hence, the coefficients of determination (R2) are 0.99 and 0.94 for Ta and RH, respectively, as shown in Fig. 7. As a result, ENVI-met results are reliable to predict the thermal performance of the optimization model Nasrollahi and colleagues (Nasrollahi et al., 2017).

2.5. Capabilities and limitations

The capabilities of the proposed methodology and the optimization model are detailed below.

(1) The most contribution is achieving optimized urban canyon ratios for the new residential city planning approach, based on emulating the planning of old Arab cities in contemporary cities and encouraging liveability, walkability, social interaction, and sustainability.
(2) The flexibility of applying the proposed methodology to other residential complexes in the new desert Egyptian cities.
(3) Providing diverse cases of different H/W to suit different residential building gatherings.
(4) Studying the effect of vegetation, shading strategies, and water fountains on the OTC.

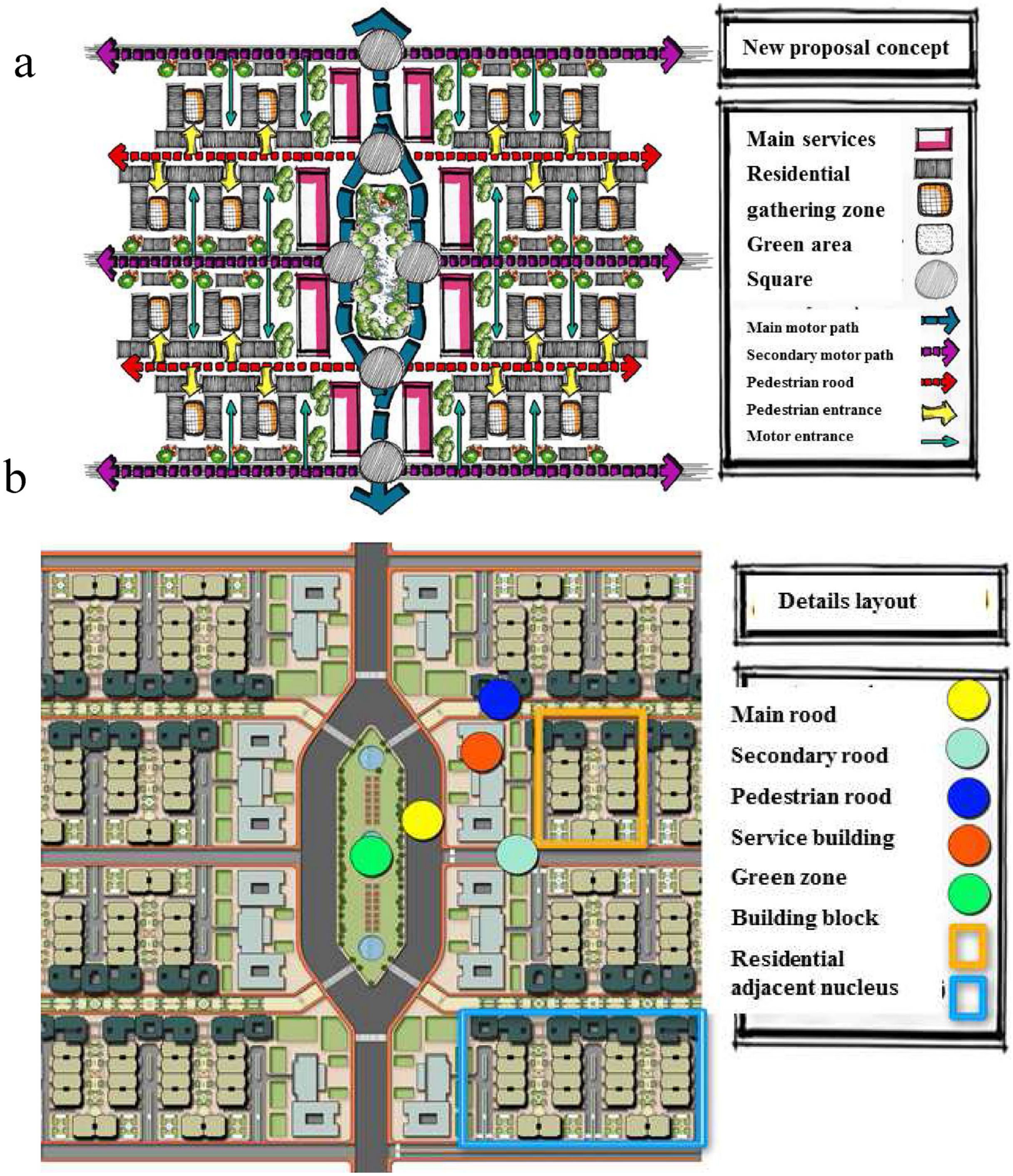


Fig. 6. The new planning proposal concept (author).

(5) Presenting the preliminary study of air quality in outdoor spaces which is represented in determining the concentration of CO_2.
(6) Usability of studying the thermal performance of scenarios in the early design stages.
(7) Expansion potential of the methodology to include several developed scenarios.

On the other hand, the limitations and shortcomings are detailed below.

(1) The study focused on two fixed heights for residential buildings (15 m and 12 m) and not on the varied height between buildings.
(2) The methodology ignored the other parameters of the air quality index.

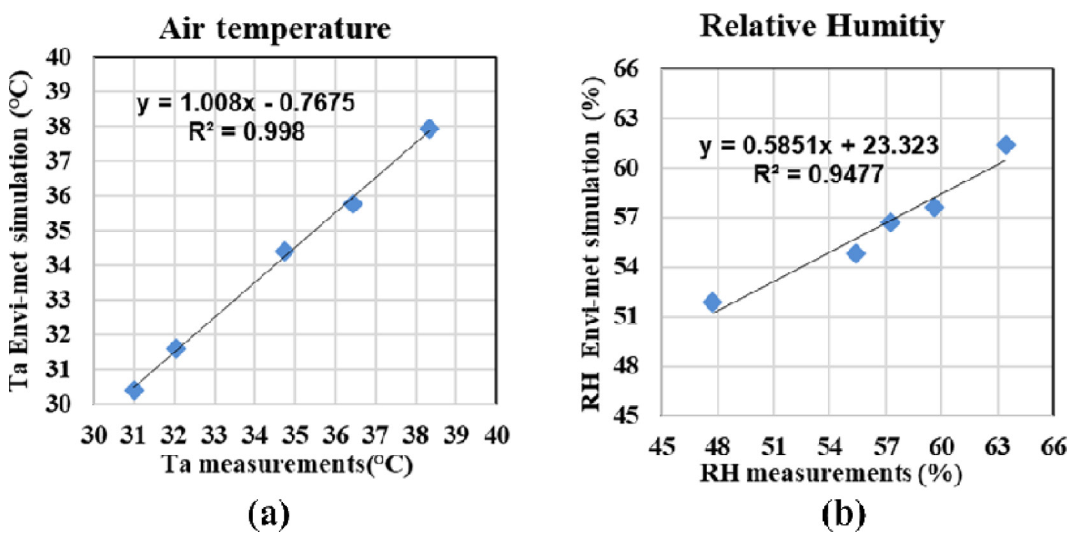


Fig. 7. The Linear regression of; a) air temperature and b) relative humidity inside the courtyard.

(3) Ignoring strategies such as the Albedo effect, and shading ratio and height for improving OTC.

3. Results and discussion

3.1. Outdoor thermal comfort assessment

Fig. 8a shows the pattern for temperature and PET for the 8 cases and base cases. Air temperature for the outer environment between buildings ranged from 30.02 °C to 40.1 °C, during the study period from 8:00 to 20:00. Meanwhile, air temperature reduction by applying the 8 cases for the optimization model ranged from 25.85 to 37.33 °C. Hence, the average of the maximum Ta reduction is 5.34 and 4.66 °C in Case 1 and Case 5, respectively. Additionally, the reduction values were between 1.44 and 7.83 °C. Thus, the improvement occurred as a result of depending on the semi-enclosed courtyard with an aspect ratio of 1.5 in the optimization model that led to providing self-shading by the surrounding buildings; reducing solar radiation exposure and discomfort hours. Due to the open side of the courtyard that is directed to the north orientation, the wind speed has significantly increased inside the courtyard with an average of 4.78 m/s compared with 2.84 m/s in the base case.

As a consequence of improving the climatic parameters, the PET index was improved in the optimization model compared with the base case, as shown in (Fig. 8b). So, for most of the study hours, the optimization model is located between slightly warm, warm, and hot ranges, in contrast to the PET values of the base case that are located in very hot and hot ranges. Finally, the cases of the optimization model assisted in reducing PET by an average of 13.3 °C, 12.64 °C and 11.62 in case 1, case 2, and case 5, respectively, within a range of 4.1 °C−19.3 °C. That result is compatible with the results of Sun et al. (2022) that proved deep canyons led to reducing solar absorption and it is useful for hot areas. It can be concluded that depending on courtyards, with deep canyons ratios such as 1.825, is more effective than using shallow canyons with a ratio less than 1.25; despite their improvements. Consequently, case 1 and case 5 are considered the optimal solution for building heights of 15 m, and 12 m, respectively. Hence, the developed scenarios will be applied to these cases to improve the urban morphology and, accordingly, improve the OTC and air quality as shown in the next section.

3.2. The effect of integration of urban mitigation strategy on outdoor air temperature

The results of applying the four developed scenarios to the optimal cases were obtained by ENVI-met software and the LEONARDO tool as shown in Fig. 9. It can be observed that the developed scenario no.3 of adding trees and semi-shading and developed scenario no. 4 of adding trees, semi-shading 50%, and fountains achieved the maximum reduction of outdoor air temperature (Ta). Due to increasing the shading area and the green area, the solar radiation decreased. Moreover, in case 1, the average of Ta reduction is 2.13, 0.84, 2.69, and 3.15 °C by applying scenarios 1, 2, 3, and 4, respectively. Meanwhile, the range of Ta redaction is from 0.72 to 3.49 °C. On the other hand, in case 5, the average

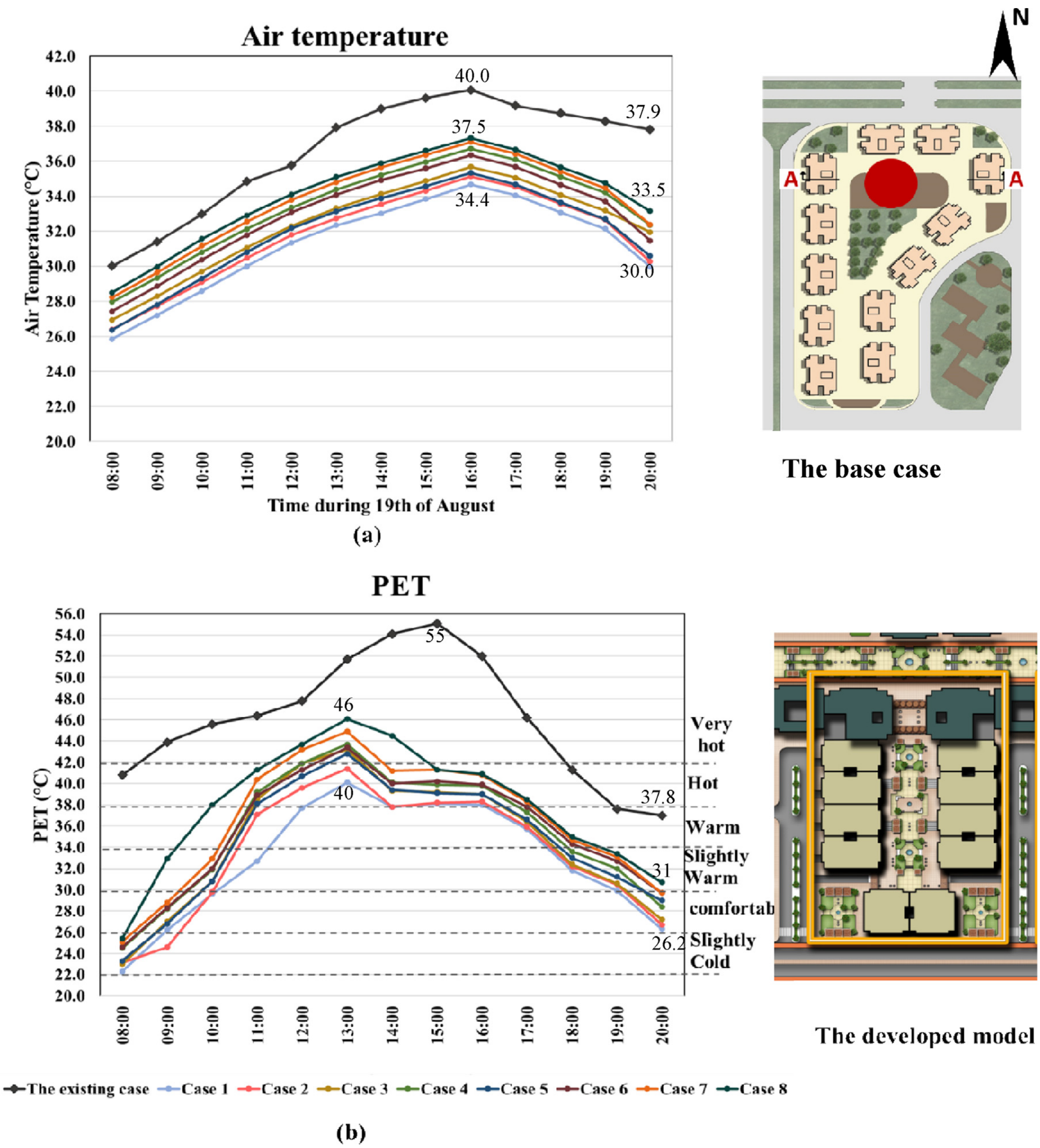


Fig. 8. The PET and temperature pattern for different scenarios; a) Ta and b) PET (author).

temperature reduction is 1.66, 1.33, 1.93, and 2.17 °C by applying scenarios 1, 2, 3, and 4, respectively, while the range of Ta redaction is from 0.26 to 2.48 °C. Hence, the maximum Ta inside the courtyard after applying the developed scenarios in case 1 and case 5 is 33.77 and 33.98 °C, respectively compared with 40.1 °C in the existing case. This result is inconsistent with the results of Mahmoud and Abdallah (2022) who obtained a Ta reduction value of 5.39 °C by applying the hybrid strategy of shadings and trees. It can be concluded that hybrid scenarios such as adding trees and semi-shading 50%, besides adding trees, semi-shading 50% and fountains are more effective than using semi-shading 50% only without any vegetation area as in scenario 2.

3.3. The effect of the optimal cases of the developed model and the 4 different scenarios on T_{mrt} and PET

Fig. 10 elaborates the T_{mrt} for the optimal cases (case 1 and case 5) and the developed scenarios. It can be seen that all the scenarios achieved a significant reduction from the optimal cases during the

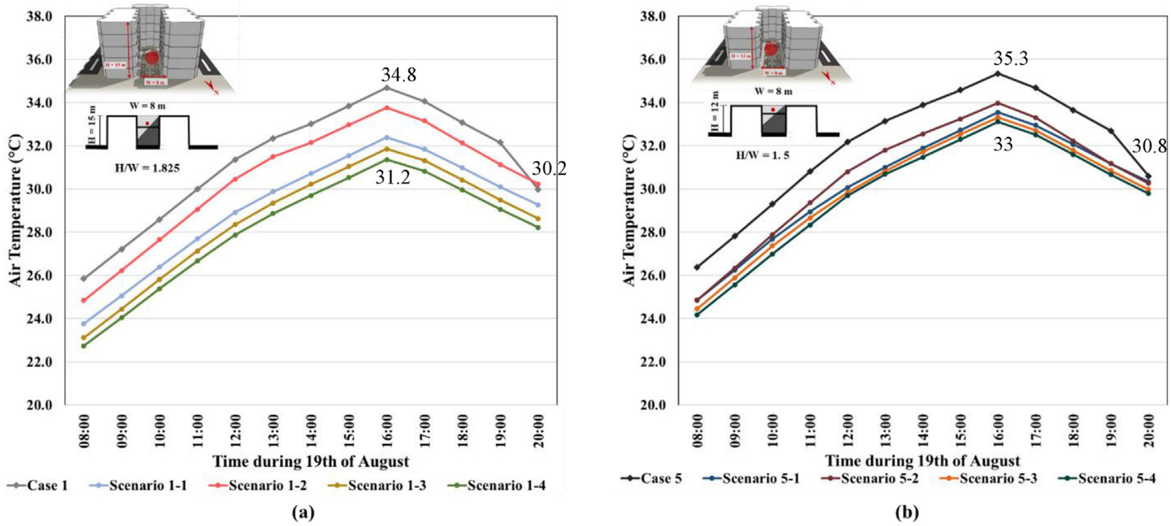


Fig. 9. The air temperature of the two optimal cases with integration 4 different scenarios; (a) Case 1 and (b) Case 5 (author).

study period until 17:00. After that the sun begins to set, the improvement begins to be very limited. Further, the highest reduction values of T_{mrt} are 9.72 and 9.60 °C in case 1, and 21.9 and 19.43 °C in case 5 by applying scenario 3 and scenario 4, respectively. This result is inconsistent with the results of Mahmoud and Abdallah (2022), as the reduction value was around 27.8 °C. Consequently, the average T_{mrt} reduction was 5.62 °C, 0.64 °C, 5.68 °C, and 5.8 °C in case 1; in addition to 6.08, 3.4, 8.52, and 7.01 °C in case 5 by applying scenario 1, 2, 3, and 4 respectively. The result is compatible with the previous study by Chen and colleagues (Chen et al., 2021b) that obtained 9.2 °C.

On the other side, the hourly PET values are illustrated in Fig. 11. The developed scenarios play a critical role in reducing most PET values and making them fall in the range between comfortable and warm during the study period. In case 1, the average reduction of air temperature is 3.8, 1.9, 4.74, and 5.25 °C by applying scenarios 1, 2, 3, and 4, respectively, while air temperature reduction ranged from 0.5 to 7.1 °C. On the other hand, in case 5, the average air temperature reduction is 4.43, 1.53, 5.19, and 5.69 °C by applying scenarios 1, 2, 3, and 4, respectively, while the range of Ta redaction is from 0.5 to 11 °C. That result is inconsistent with the result of Mahmoud and Ragab (2020) which reached

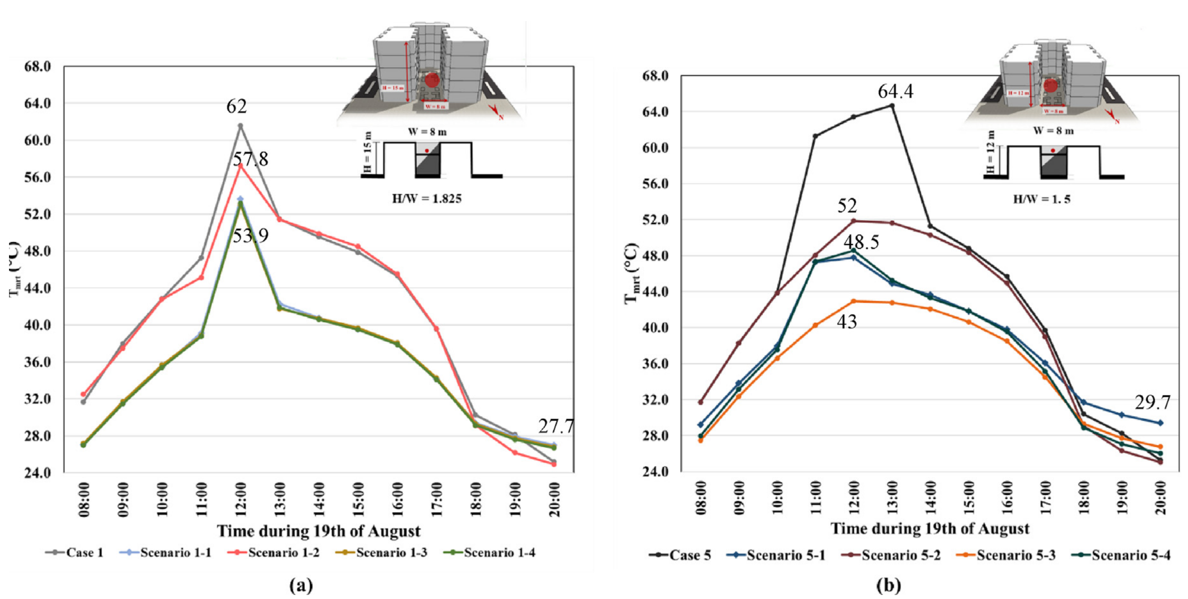


Fig. 10. The ENVI-met results of T_{mrt} of the 2 optimal cases and the 4 different scenarios; (a) Case 1 and (b) Case 5 (author).

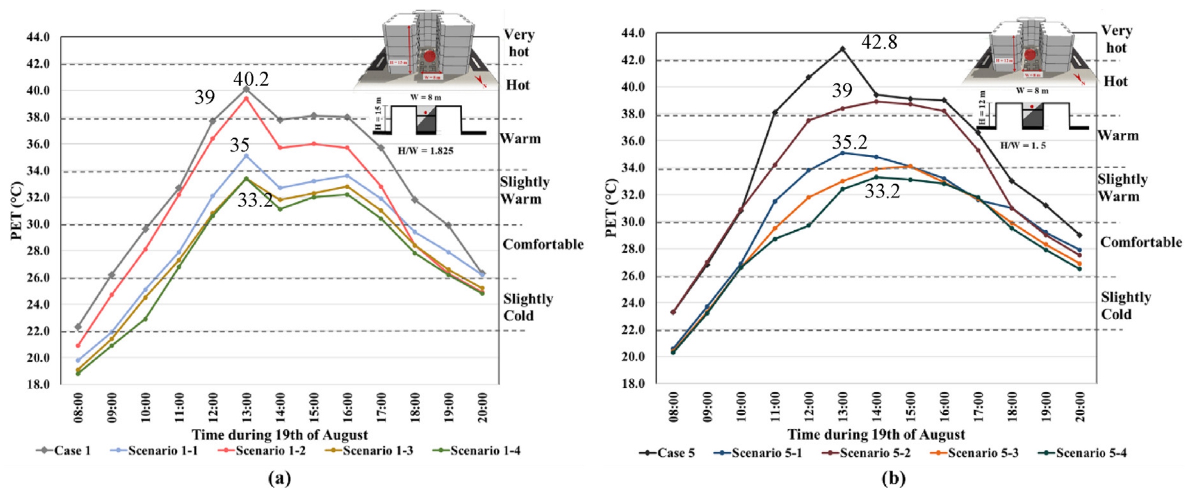


Fig. 11. The PET values of the 2 optimal cases and the 4 different scenarios; (a) Case 1 and (b) Case 5(author).

13 °C, the results of Mahmoud and Abdallah (2022) which reached 18.6 °C, and the result of Abdallah and Mahmoud (2022). So, all scenarios presented an improvement during the study period except at 13:00 and 15:00 because of the high solar radiation and the outdoor air temperature. However, the maximum averages of PET values in case 1 and case 5 are 30.88 and 33.07 °C, respectively, compared with 46.1 °C in the base case. Eventually, the distribution maps of T_{mrt} of 2 optimal cases (case 1 and case 5), and the four developed scenarios, are illustrated in Fig. 12.

Fig. 12 shows the temperature distribution for different scenarios based on the simulation of ENVI-met. Reduction of courtyard surface temperature in two optimum cases (1 & 5) is due to using scenario no. 3 (hybrid scenario shading and adding trees). Adding this scenario achieved a temperature difference with an average of 9.3 K inside the inner courtyard of deep canyons, especially at 14:00 in a different location. This affects strongly the thermal comfort of residents doing different activities and reduces transfer of outer heat to indoor building environments, and energy consumption for the building. This temperature reduction is equivalent to a previous study Liao and colleagues (Liao et al., 2021). In conclusion, applying the hybrid scenario of adding trees, 50% semi-shading and fountains achieved the highest reduction of Tart and PET. This causes improvement of OTC. Thus, it can be seen that the methods of planning residential areas, types of pedestrian and vehicular traffic, and their relationship with serving residences, all have a direct impact on the social/administrative aspects and the responsibility model. Thus, improving the urban canyon of the new planning proposal with a comfortable OTC have a direct impact on the social/administration aspect for residents; encouraging walkability and social interaction.

3.4. Evaluation of outer air quality (CO_2)

For studying the air quality in outdoor spaces, a set of concentrations such as PM 2.5, PM 10, CO_2, CO, NO_2, SO_2, and O_3 should be measured or simulated. Consequently, ENVI-met was utilized to simulate the concentration of CO_2 inside the courtyard in the optimization model and three developed scenarios. First of all, the concentration of CO_2 in the base case was very high; ranging from 401.67 ppm to 414.38 ppm, which exceeds the normal range in outdoor spaces at 400 ppm Miao and colleagues (Miao et al., 2023). This is due to the lack of trees and the high temperature inside the courtyard with an aspect ratio of 0.24. On the hand, applying the optimization model and the developed scenarios assisted in improving the air quality inside the courtyard and reducing the concentration of CO_2 to be in the normal range, as a result of increasing the vegetation area. Thus, as shown in (Fig. 13a), the average of the CO_2 concentration is 396.95, 404.59, 398.73, and 399.89 ppm in case 1; by applying scenarios 1, 2, 3, and 4, respectively compared with 408.89 ppm in the base case.

As a result of applying a vegetation strategy inside the courtyard, self-shading led to reducing Ta, and the semi-enclosed courtyard led to increasing wind speed (compatible with the results of (McMullan and Angelino, 2022; Nosek et al., 2022)). As elaborated in (Fig. 13b), the average CO_2 concentration is 397.58, 403.89, 398.99, and 400.52 ppm by applying scenarios 1, 2, 3, and 4, respectively. So, the

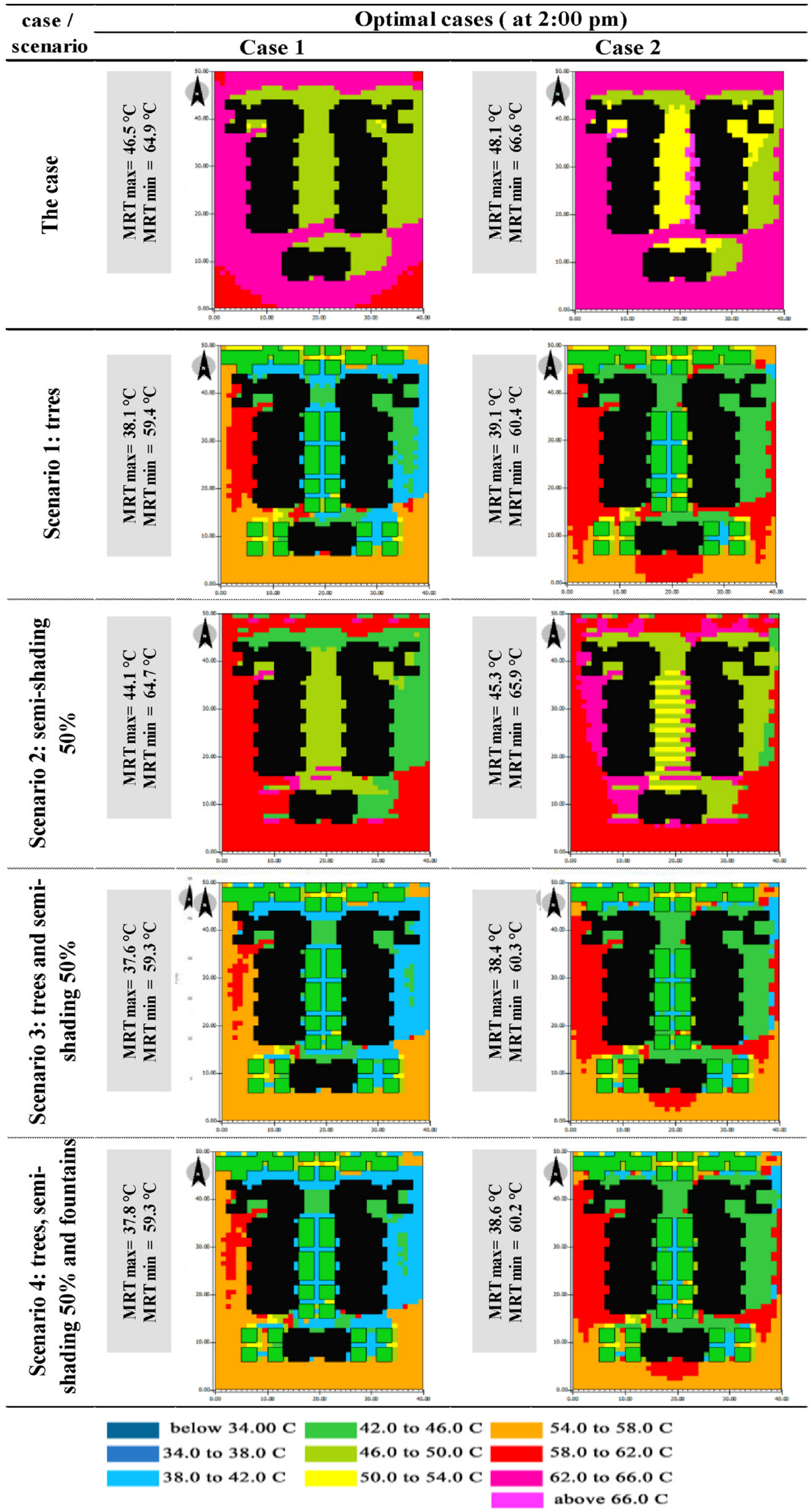


Fig. 12. The Thermal distribution map of the 2 optimal cases and the 4 different scenarios at 2:00 pm (author).

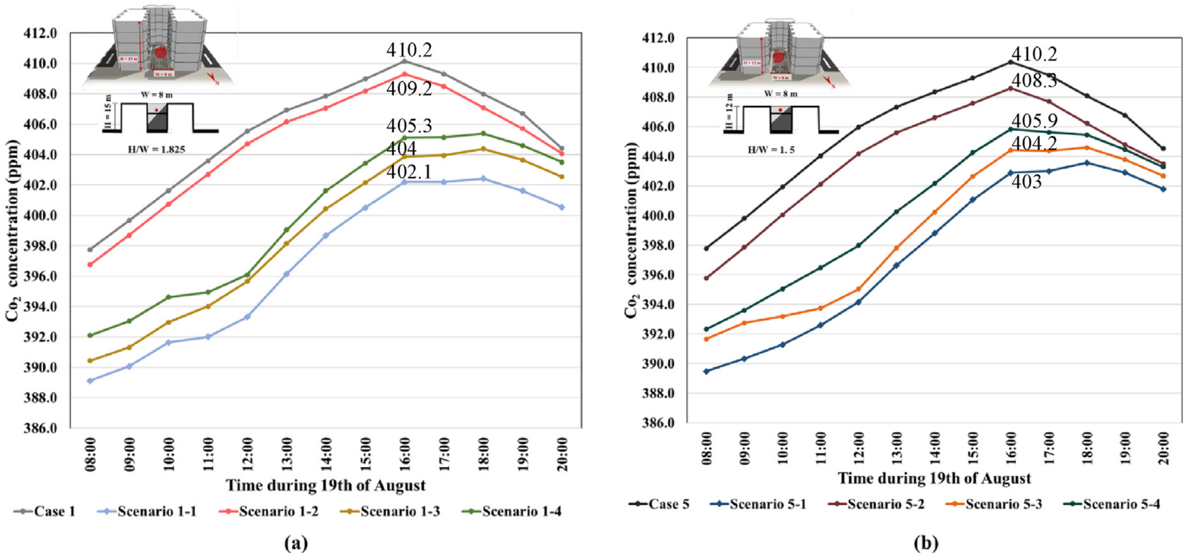


Fig. 13. The CO_2 concentration of the 2 optimal cases and the 4 different scenarios; (a) Case 1 and (b) Case 5(author).

reduction of CO_2 concentration ranged from 0.34 to 12.33 ppm. It can be concluded that the optimization model and the developed scenarios succeed in reducing CO_2 in the courtyard; leading to better air quality for users.

3.5. Conclusion

This study aims to propose new planning approach that achieve residents' thermal comfort inside the courtyards of residential complexes based on improving the urban canyon ratio in an existing residential complex in New Assiut city as a base case. The results can be summarized as follows.

(1) Buildings of deep canyon (W = 8), and building height equal 12 and 15 with aspect ratios 1.825 and 1.5, achieved the optimal reduction of air temperature and PET.
(2) Integration of Trees and trees and 50% semi-shading achieved a significant reduction in outdoor CO_2 concentration inside the courtyard with a CO_2 range from 0.34 to 12.33 ppm, especially for an urban canyon with an aspect ratio of 1.825.
(3) Integration of urban mitigation strategies (trees and hybrid scenario), to the deep canyon with an aspect ratio (H/W) equal to 1.5, achieved more significant education for PET with an average of 33.07 °C compared with the base case.
(4) A higher influence of integrating hybrid scenarios to the inner deep courtyard with an aspect ratio (H/W) equals 1.5, compared with a courtyard with an aspect ratio (H/W) equal 1.825 according to T_{mrt} and a temperature difference of 9.7 K.

The study has proved that the optimization of a new planning proposal with a deep canyon (4 floors and five floors with canyon width = 8 m), and integration of a hybrid scenario (tree and 50% shading), led to reducing solar radiation and increasing wind speed and achieving residents' thermal comfort and outer air quality. These optimum ratios can be integrated in planning new residential compounds and new cities planning in the desert. So, it is considered the main contribution.

Author contribution

Mohamed Eid conceived the idea, both authors wrote and developed, improve the paper, and read and agreed to the published version of the manuscript. A. Abdallah conduct the measurement and performed data analysis. R. Mahmoud built and validated the simulation model, performed data analysis.

Conflicts of interest

No potential conflict of interest was reported by the authors.

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