

URBAN IMPACTS ON VENTILATION IN HOT-HUMID CLIMATES: MULTI-HEIGHT BUILDINGS IN BASRA

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Abstract

The purpose of the study was to identify the most influential urban design factors for improving ventilation in the open spaces of multi-storey residential complexes in Basra's hot-humid climate. **Methods:** using a case study approach, we conducted ENVI-met v5.9 simulations for 16 models of two spaces within the "Al-Amal Residential Complex" during summer and winter. Four models reflected existing conditions, while 12 involved scenarios that adjusted building height, distance between buildings, and orientation, and were measured against environmental indicators: air temperature (T_a), wind speed (WS), sky view factor (SVF), and predicted mean vote (PMV). **Results** showed that building height is the most significant factor in improving ventilation and providing self-shading, followed by north-west orientation. Distance between buildings ranked last due to the trade-off between achieving urban breathing and increased solar exposure. The research recommends adopting compact vertical blocks with a north-west orientation and integrating vegetative or artificial shading to compensate for reduced self-shading and enhance social interaction.

Keywords: urban design factors; ventilation; multi-storey residential buildings; thermal comfort; ENVI-met; Basra.

Introduction

The outer urban spaces between residential buildings play a pivotal role as a vital connecting fabric of the built environment and as an attractive medium for social interaction among residents. However, the positive activation of these spaces requires the provision of thermal comfort that allows human presence in them throughout the day, summer and winter, especially in hot, humid climates where natural ventilation is a decisive factor in improving the microclimate.

It is clear from reviewing the previous studies that most of them investigated the influence of a single factor on outdoor space ventilation, while a few studies, such as Yola et al. (2022), began to explore the interaction between two factors (building height and canyon orientation). Although these studies contributed to an in-depth understanding of each factor, none of them provided a comparative assessment of three key design factors simultaneously — building height, distance between buildings, and building orientation- nor did they examine how these factors interact within an integrated urban context.

This knowledge gap is the starting point for this research. It examines the potential of urban standards to achieve effective natural ventilation in spaces between multi-storey residential buildings in Basra's specific climatic context, characterised

by hot, humid summers and mild winters with high relative humidity. The study aims to provide recommendations for urban designers to create environmentally successful urban spaces.

Therefore, the research will examine three urban design factors—building heights, distances between buildings, and building orientation—in improving ventilation in outdoor open spaces between multi-storey residential buildings in Basra's hot, humid climate.

Literature Review

This section represents the theoretical framework for the study, which includes two main parts, as shown in Fig. 1. The first part explores the interrelationships among the environmental indicators, including wind speed (WS), air temperature (T_a), sky view factor (SVF), and predicted mean vote (PMV) in hot-humid climates. The second part examines the role of urban design factors, including building height, distance between buildings, and building orientation in controlling outdoor ventilation and thermal performance.

Interrelationships among environmental indicators

In hot and humid climates, ventilation performance is directly related to environmental indicators on the one hand and to the distribution of buildings and street networks on the other hand. Surrounding buildings reduces WS around building blocks, and

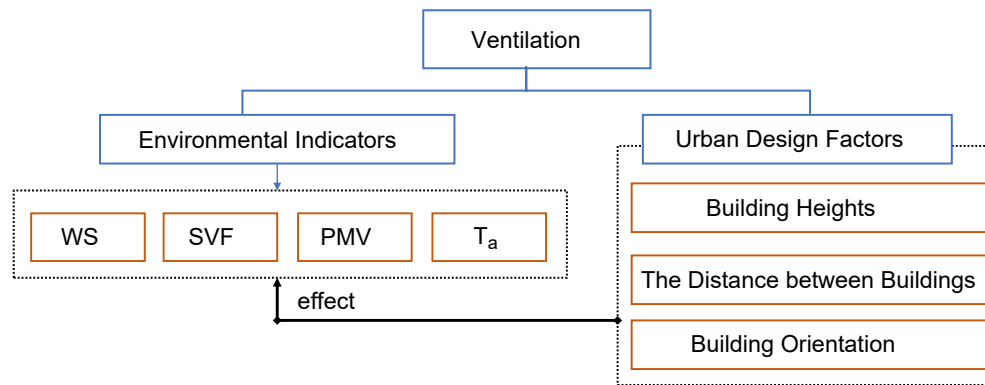


Fig. 1. The parameters identified in the theoretical framework (Source: Authors)

block height and road width affect wind pressure differences (Gülten and Öztop, 2020). Ambient temperature is considered the most influential environmental variable in hot regions, followed by sky view factor (SVF), and then the aspect ratio. Low SVF values would also help mitigate city air temperatures in high-density neighbourhoods during heatwaves (Fan et al., 2024). WS is the primary driver of natural ventilation and relief of high humidity.

Urban configurations that allow air to pass through, such as oriented buildings and courtyards, increase local WS. This increase enhances thermal comfort by generating evaporative cooling. The spaces between high-density buildings are characterised by thermal discomfort in summer due to reduced WS and air stagnation caused by these buildings, as obstacles (Palusci et al., 2022). A direct relationship exists between SVF and daytime heat gain: higher SVF values increase exposure to direct solar radiation. This will lead to raised T_a and surface temperatures. Low SVF values provide self-shading that protects the outer spaces from radiative thermal gain and keeps them cooler. Furthermore, the SVF can be controlled by adjusting the length-to-width ratio of a space to create shaded areas that prevent heat loss and promote passive heat storage in surfaces during winter. At the same time, these shaded areas reduce the effect of urban heat islands in summer (Pouri et al., 2025).

Afforestation elements play a decisive role in adjusting wind movement in hot, humid climates. A study by Dissanayake et al. (2023) compared different planting arrangements within square-shaped open spaces, and their results showed that the dispersed (random) planting pattern achieved the greatest improvement in average WS.

Ventilation is associated with both WS and shading that resulted from SVF reduction. Therefore, average WS between 1.5 and 3.6 m/s is preferable to reduce cold stress in winter, while 1.5 m/s is considered relatively calm in summer. These values vary with building height or environmental treatments (Abdalazeem et al., 2024). An increase in

WS also reduces physiological thermal stress at air temperatures below or above 35°C, depending on decreasing humidity (Bröde and Kampmann, 2023).

According to Musa et al. (2022), SVF optimally ranges from 0.38 to 0.65. Outdoors, in hot, humid climates, the acceptable PMV range is between −4 and +4. To achieve PMV moderation, WS must be high (1 to 2 m/s) to promote evaporative cooling, while reducing mean radiant temperature via shading elements, such as umbrellas, because direct solar radiation quickly raises the PMV value towards +3 or +4, and preferably, T_a should be between 24°C and 28°C with air movement (Bröde and Kampmann, 2023).

Urban design factors influencing natural ventilation

There are studies that investigated the influence of urban characteristics on natural ventilation at the urban level. Salem and Othman (2024) confirmed that the spaces between buildings were the most influential on ventilation quality, followed by the design of the street grid, and then by architectural building characteristics. Similarly, W. A. A. Mohamed (2022) concluded that street density is the dominant element in increasing the possibility of greater air permeation within residential complexes. This enhances the positive relationship between the openness of the urban fabric and the efficiency of natural ventilation.

Building heights: Height influences the vertical thermal gradient (Li and Donn, 2017). The average temperature decreases by 0.65 degrees Celsius for every 100 meters of height. This confirms the relationship between building height and local climate change. Yola et al. (2022) analysed the morphology of urban canyons (the space between buildings) in Kuala Lumpur (hot, humid climate). Their study found that increasing building height lowers the mean radiant temperature, especially in the morning and evening, but reduces WS inside the canyon when the increase is uniform on both sides. The study also noted the role of canyon orientation in modifying these effects. Consequently,

increasing the height-to-width ratio (H/W) positively affects the thermal environment by reducing thermal stress in the area. This is because it enhances shading and reduces the amount of solar radiation reaching the ground surface. Building height affects solar radiation, temperature, and WS. Elevations increase shading, which lowers the absorbed solar radiation and reduces the urban heat island effect. Tall buildings also act as thermal chimneys, drawing hot air upwards, away from the pedestrian level (Palusci et al., 2022).

By using ENVI-met simulations, Ragheb et al. (2024) demonstrated in their study in Egypt that building height significantly affects microclimatic conditions and pedestrian thermal comfort. They recommended that urban planners consider building heights and layouts to improve local climatic conditions. It has been noticed that the height-to-width ratio (H/W) affects T_a : a lower ratio increases solar absorption by road surfaces. That is why canyons with a lower H/W ratio are exposed to higher diurnal heat (Kareem and Mahmood, 2025) and ground surface temperatures are lower in higher-altitude residential buildings (Zheng et al., 2019). Salameh et al. (2023) noted in their study that the variety of building heights contributes to lower T_a than in moderate-contrast cases. Placing a high-rise next to a low building increases WS by up to 90 % while lowering the temperature by about 1 °C. Hence, the strategic integration of a limited number of high-rise buildings can enhance alley ventilation and reduce heat (Salameh et al., 2023).

Distance between buildings: Distance relates to “urban breathing”; it creates open spaces that allow airflow at pedestrian level. Therefore, integrating semi-open spaces with buildings significantly improves ventilation (Juan et al., 2021). However, a lower ground coverage ratio (10 %) increases annual solar radiation compared to a higher ratio (50 %), which provides greater shading (A. M. S. Mohamed, 2022). For thermal comfort, “semi-enclosed” spaces are preferred for daytime use, while “open” spaces are best for night time use (Lam and Hang, 2017). By design, scattered point layouts (wide spaces) are better ventilated for low site coverage, whereas closed styles with small distances suit very cold climates. The relationship between the building height and horizontal distance remains decisive for ventilation control (Ma and Chen, 2020). CFD-based studies have shown that ventilation performance is very sensitive to the spacing between buildings, since the maximum airflow is achieved when the separation distance is approximately equal to the height of the building, as both frontal and angular flows contribute to the movement of air around the building aggregates (Ghulam et al., 2021; Ayo and Mohd-Ghazali, 2024). The square spaces resulting from buildings’ setbacks of 8 m from the street and

16 m from corridors achieve better ventilation for both single- and multi-high-rise buildings (Xu et al., 2022).

Building orientation: Orientation is a pivotal factor in natural ventilation and solar radiation control in humid, hot areas, and aims to minimise thermal gain and maximise the effect of prevailing winds. Effective cross-ventilation depends mainly on the building’s orientation relative to the local wind direction (Mahmoud and Ghanem, 2019). Optimal orientation varies by climate, but in hot, humid regions, north-west orientation is often favourable (Abdelhafez et al., 2022). Moreover, the building form and orientation significantly influence the conditions of surrounding microclimates (Derakhshan and Karimimoshaver, 2026). Therefore, there is a need to make site-specific design decisions rather than following general rules, as orientations affect surface heat levels differently throughout urban contexts (Derakhshan and Karimimoshaver, 2026). At the urban level, tall buildings play a dual role depending on location. According to Lin et al. (2026), locating buildings in the western part slows prevailing winds (see Fig. 2, H2), while their location in the northern part (H3) reduces WS and increases airflow between buildings. Their placement in the north-western corner (H4) achieves balanced ventilation distribution by mitigating the decrease caused solely by western obstructions (Lin et al., 2026).

To summarise, previous studies emphasise the individual effects of building height, distance between buildings, and building orientation on natural ventilation and thermal comfort in hot-humid climates. Yet, their combined and comparative assessment remains unexplored. Most reviewed studies have focused on isolated variables or paired interactions (e.g., height with orientation), but none have examined the impact of all three factors within an integrated urban context, especially in a climate like Basra’s. Therefore, the current study’s comparative simulation approach is important to conduct. To carry out this comparison, it is necessary to use an accurate physically based climate simulation tool to assess the impact of three urban design factors on specific environmental indicators (WS, T_a , SVF, and PMV) that control ventilation quality. For this purpose, the ENVI-met v5.9 was chosen, a three-dimensional climate model based on fluid dynamics and thermodynamics that analyses airflow around and between buildings, along with radiation and heat exchange between surfaces and the atmosphere (Bruse and Fleer, 1998). However, the reliability of such a simulation largely depends on the accuracy and reliability of the model used. The effectiveness of the ENVI-met model in assessing thermal comfort and ventilation performance in outdoor spaces has been demonstrated in a growing body of research conducted in similar climates. One of

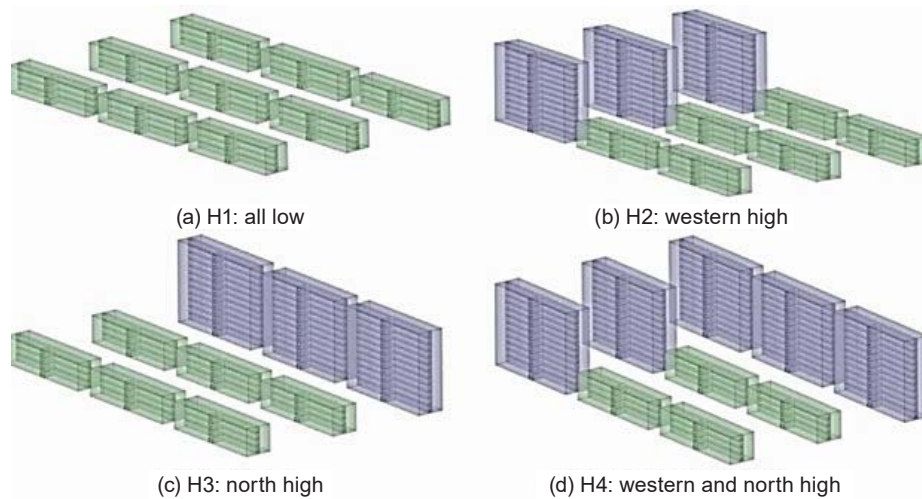


Fig. 2. The relationship between building height and orientation (Lin et al. 2026)

these applications is studies conducted in Basra (Almansor et al., 2026) and Baghdad (Ridha, 2022; Musa et al., 2023), as well as other hot-humid regions such as China (Ma and Chen, 2020; Liu et al., 2024; Schöneberger et al., 2025). Taken together, this evidence confirms the suitability of ENVI-met for use in this research.

Methods

The research examined the impact of three urban design factors — building heights, distance between buildings, and building orientation — on improving ventilation in outdoor spaces between multi-storey residential buildings in Basra city. To achieve this, a case study approach was adopted, selecting two sites within the Al-Amal residential complex in Basra city. Building on this selection, 16 models were simulated using ENVI-met v5.9 to assess the influence of these urban design factors under both summer and winter conditions. These models encompassed four base cases and 12 proposed models, representing three

distinct scenarios (see section 3.2 for more details). Numerical data from both case studies included four environmental indicators (WS, Ta, SVF, PMV) for summer and winter. For each of these scenarios, the mean of each environmental indicator was calculated in Excel. Delta (Δ) was calculated as the difference between the scenario and the base case, with the direction of improvement noted (see section 3.3). The study analysed numerical data and ENVI-met coloured maps both statistically and visually.

Case study selection

Basra city, the southernmost part of Iraq, is recognised for its extreme climatic conditions. Its climate is extremely hot and humid, with peak temperatures exceeding 50°C and scarce rainfall, posing serious challenges to achieving thermal comfort in outdoor urban spaces. Al-Amal residential complex, located in the north of Basra city (Fig. 3) was chosen as the field study area. The study selected two models of vertical building arrangements as

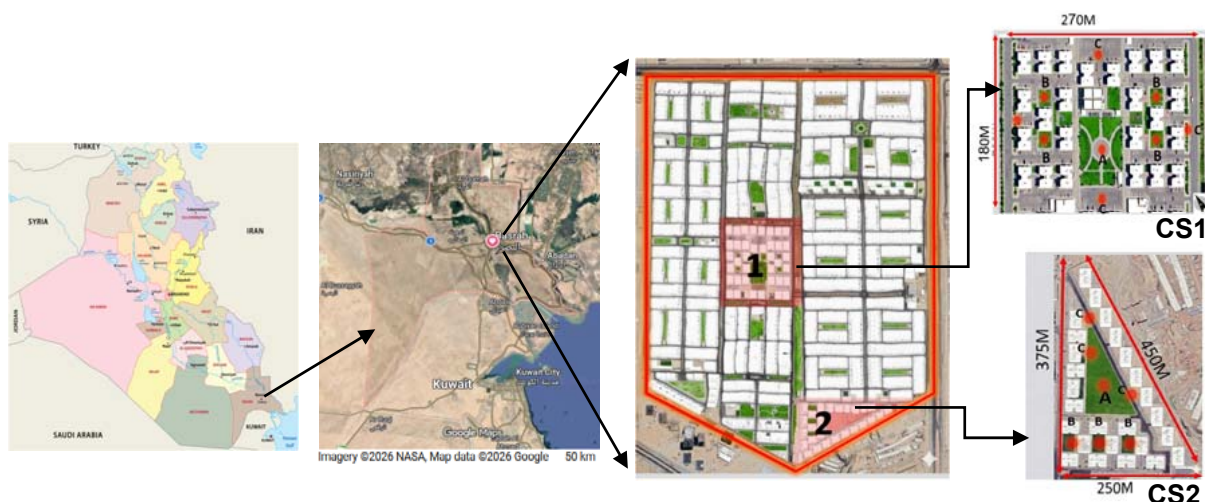


Fig. 3. The geographic location of case studies CS1 and CS2 (Annotated by the authors, source: Google Earth/Map)

case studies. This choice was made because they represent diverse urban patterns and block organisations, allowing for relatively generalized results in similar contexts. They are as follows:

- **Case Study 1 (CS1) (rectangular arrangement):** consists of 24 residential blocks with a height of four floors (G+3) with an area of 4.86 hectares. These blocks are organized in a symmetrical clustering around a wide central courtyard (Central Plaza), designed to promote social interaction, with small interspersed green spaces between the buildings, as shown in Fig. 3.

- **Case Study 2 (CS2) (triangular arrangement):** it is characterized by a different geometric configuration with an area of 4.68 hectares, where it includes 9 buildings with a height of seven floors (G+6) distributed according to a linear graded organization, in addition to 16 buildings with a height of four floors (G+4) distributed in an aggregate style. These elements converge around a large central area, with green spaces integrated into the assembly pattern, as shown in Fig. 3.

Simulation and scenario design

To achieve the research aim, the study conducted an environmental analysis of the two selected case studies (CS1 and CS2) by creating three-dimensional digital models using ENVI-met v5.9, an advanced tool for simulating local climate. The ENVI-met program was employed in this study to simulate the urban microclimate of complex urban environments on a sound physical basis. The program's proven reliability in thermal comfort aligns with local meteorological station data (Ridha, 2022), as evidenced by simulation outcomes, and has been verified across multiple hot-humid climates (see Section 2 for detailed sources). The model has

demonstrated acceptable accuracy in simulating wind speed and air temperature (Liu et al., 2024), which are essential indicators in the current study. Recent evaluations in subtropical and tropical contexts have shown that ENVI-met performs best during summer — the most important season for evaluating thermal comfort in Basra — when the model's results exhibit the fewest errors during this period (Liu et al., 2024). Due to the model's reliability in similar climatic contexts, it was chosen for the current research.

The modelling included all the constituent elements, including building blocks, vegetation, and the network of roads and sidewalks, to ensure accurate simulation of thermal interactions between surfaces and the atmosphere. To ensure simulations under the city of Basra's critical climatic conditions, data from the hottest and coldest days were selected from official meteorological data that represent the peak of climate extremes in Basra governorate for 2025 (Table 1 and Fig. 4). The simulation included extracting readings for four environmental indicators (WS, Ta, SVF, and PMV) at 15:00, as this time corresponds to the peak of daily heat stress. Nine receptors were strategically distributed in CS1 and eight in CS2 in three zones in each model to cover the morphological diversity: **Zone A** represented the central plaza; **Zone B** represented the spaces between buildings, and **Zone C** represented the area in front of buildings' entrances (see Fig. 5).

Three proposed scenarios were simulated in addition to the base case of each case study (BC-CS1, BC-CS2). Each of these scenarios involved four simulated models, with each pair related to a case study during summer and winter. In total, 16 proposed models were simulated (see Table 2).

Table 1. Daily climatic data used as input for ENVI-met simulations (extreme days in Basra, 2025) (Source: Basra Meteorological Office)

		Temperature		Wind		Relative Humidity	
		max	min	direction	m/s	min	max
Summer	11/07/2025	51	35.4	297°	3.1	7	22
Winter	2/02/2025	16.9	8	270°	2.8	40	90

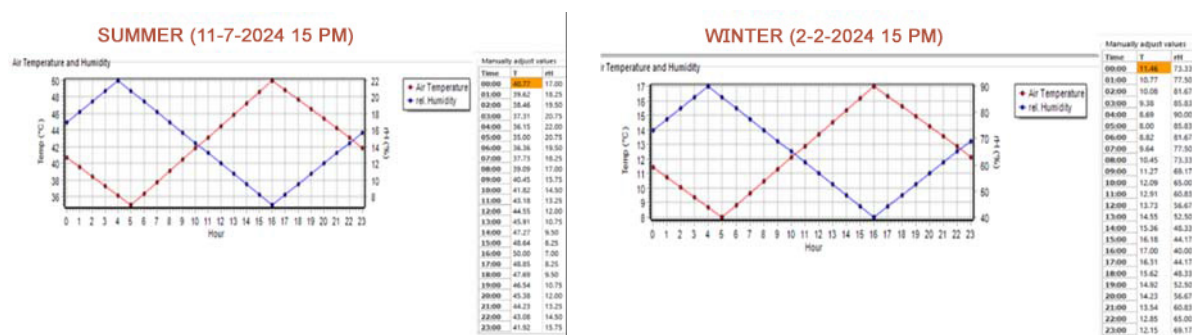


Fig. 4. Climatic inputs for the hottest and coldest day in Basra city in the ENVI-met program v5.9. (Source: Authors)

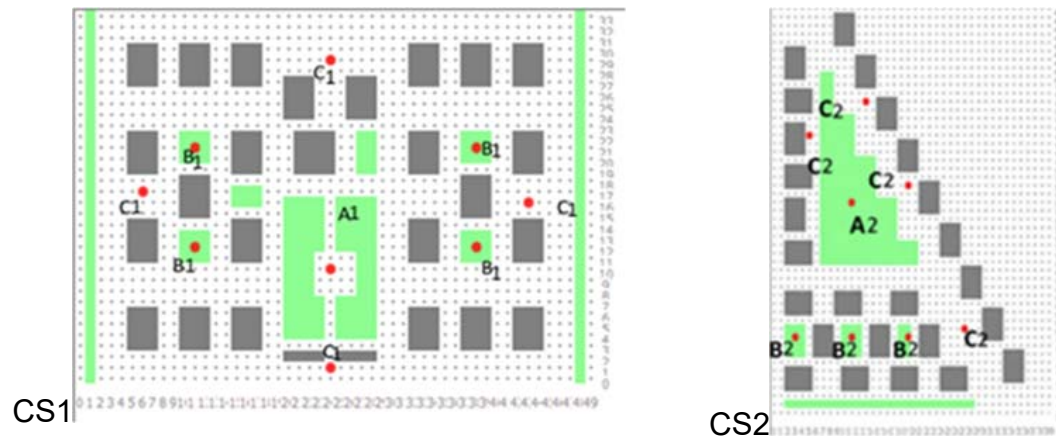


Fig. 5. 3D simulated digital model of CS1 and CS2 using the ENVI-met program v5.9. (Source: Authors)

Table 2. The abbreviation of the proposed simulated scenarios (Source: Authors)

	CS1		CS2	
Model	Summer	Winter	Summer	Winter
Base Case (BC)	BC-S1	BC-W1	BC-S2	BC-W2
Height (H-scenario)	H-S1	H-W1	H-S2	H-W2
Distance (D-scenario)	D-S1	D-W1	D-S2	D-W2
Orientation (O-scenario)	O-S1	O-W1	O-S2	O-W2

Each scenario examined one of the three selected urban design factors during summer and winter to isolate their impact as follows:

- **Increment height of buildings (H-scenario):** increasing the number of floors of buildings in CS1 and CS2 (+3), without changing orientation and distances between buildings. This amendment was selected to represent a moderate vertical expansion reflecting the common trends in residential density projects that align with Iraqi housing standards. This scale of change is substantial enough to affect shading, wind flow, and radiant heat exchange, enabling a robust evaluation of height-related effects.

- **Changing the distance between buildings (D-scenario):** increasing the distance between buildings in CS1 by two meters and decreasing it by two meters in CS2, without changing the original orientation and height. These changes were chosen because they may affect airflow dynamics and local climate characteristics in the region.

- **Changing orientation (O-scenario):** rotating building blocks towards the north-west direction without any change in height and distance between buildings. This direction was selected as it aligns with the favourable conditions of Iraq's hot, humid climate. It can substantially influence sun exposure and wind flow patterns.

Data analysis approach

The study used a quantitative method to identify which urban design factors most effectively improved ventilation in Basra, using statistical and visual

analysis. Improvement was defined as an increase in WS, a decrease in T_a , a decrease in SVF, and a decrease in PMV towards neutral. Delta values were normalised for comparison. The average improvement per scenario was calculated, and the results from both case studies were combined by calculating the arithmetic mean of the corresponding delta values from CS1 and CS2 for each indicator, ensuring equal weighting for both configurations. Statistical findings were supported by visual analysis of ENVI-met maps, comparing environmental indicator patterns, value ranges, and spatial distributions between the base case and scenario conditions.

Results

Statistical analysis

The study conducted a statistical analysis to identify the most positive influence of urban design factors (building height, distance between buildings, building orientation) on improving the natural ventilation by enhancing environmental indicators (WS, T_a , PMV, SVF) in outdoor open spaces of two different urban models (CS1 and CS2). The study determined the required improvement trend for each environmental indicator, as shown in Table 3, as mentioned in previous studies.

The analysis began by extracting four environmental indicators (WS, T_a , PMV, SVF) from ENVI-met for each receptor in the case studies. There were nine receptors in CS1 and eight in CS2. This process was repeated across three scenarios, plus the base cases, for both summer and winter. The

Table 3. The direction of improvement required for each environmental indicator (Source: Authors)

Indicator	Summer	Winter
WS	Increase (+)	Decrease (–)
T _a	Decrease (–)	Increase (+)
PMV	Decrease (–) to (0)	Increase (+) to (0)
SVF	Decrease (–)	Decrease (–)

arithmetic mean for each environmental indicator, scenario, and case study was calculated in Excel by averaging all receptor readings. For example, in summer, the WS readings of all nine CS1 receptors in the H-scenario were averaged. Table 4 shows the scenario means.

Next, the Delta (Δ) value for each environmental indicator and scenario was calculated in Excel. The desired optimisation direction for each indicator was checked using Table 3. If an increase was the target for an indicator, the Delta was calculated as:

$$\delta = \text{Mean}_{\text{Scenario}} - \text{Mean}_{\text{BC}}$$

And if a decrease was the target for an indicator, the Delta was calculated as:

$$\delta = \text{Mean}_{\text{BC}} - \text{Mean}_{\text{Scenario}}$$

Because environmental indicators differ in units and ranges, each indicator's Δ values (for H-, D-, O-scenarios) were normalised in Excel using linear normalisation and the following equation:

$$\delta_{\text{normal}} = (\delta - \delta_{\min}) / (\delta_{\max} - \delta_{\min})$$

This normalisation process produced Δ_{normal} values ranging from 0 to 1 for each environmental indicator in each scenario, where 1.00 represents the best relative performance and 0.00 the worst. For each scenario (H, D, O), the arithmetic mean of all seven environmental indicators' Δ_{normal} values was calculated using Excel's AVERAGE function. Table 5 shows the calculated Δ for each indicator and scenario in both case studies for clarity.

Table 6 shows a consolidated view in which higher values indicate greater improvement, and lower values indicate less improvement or deterioration.

To find which urban design factor has the greatest positive impact, the scenarios were ranked in descending order by the average Δ_{normal} for each case study. The overall mean for each scenario across both case studies was then recalculated using the AVERAGE function to determine which urban design factor had the greatest overall positive effect (Table 7).

Visual analysis of simulation maps

The visual analysis of the extracted coloured maps for the four environmental indicators in the base case of CS1 and CS2, and the proposed scenarios, compared the colour distribution of what happened in Zones A, B, and C, as follows:

The base cases analysis (CS1 & CS2). The base-case results for CS1 showed that WS reached up to 3.08 m/s in summer, and 3.30 m/s in winter, while in CS2, the maximum WS was 3.42 m/s in summer and 2.80 m/s in winter. The highest values

Table 4. Arithmetic mean for each indicator and for each scenario in CS1 and CS2 (Source: Authors)

Indicator	CS1				CS2			
	BC	H	D	O	BC	H	D	O
WS -Summer	1.331	1.344	0.882	1.256	0.473	0.666	0.766	0.843
WS -Winter	1.136	1.220	0.786	1.186	0.741	0.690	1.435	0.788
T _a -Summer	48.531	48.372	48.417	48.333	48.493	48.254	48.538	48.358
T _a -Winter	16.294	16.188	16.196	16.149	16.278	16.175	16.130	15.829
PMV- Summer	8.002	8.081	8.243	8.013	8.165	7.026	8.096	7.261
PMV- Winter	–0.419	–1.011	–0.546	–0.513	–1.155	–1.081	–1.079	–0.701
SVF	0.868	0.742	0.831	0.869	0.731	0.629	0.813	0.731

Table 5. Delta Δ values (with the direction of improvement) for CS1 and CS2 (Source: Authors)

Indicator	CS1			CS2		
	H	D	O	H	D	O
WS -Summer	0.013	–0.449	–0.076	0.1938	0.294	0.370
WS -Winter	–0.084	0.350	–0.050	0.051	–0.694	–0.046
T _a -Summer	0.159	0.114	0.198	0.239	–0.045	0.134
T _a -Winter	–0.107	–0.099	–0.146	–0.102	–0.147	–0.448
PMV- Summer	–0.078	–0.241	–0.011	1.139	0.069	0.904
PMV- Winter	–0.592	–0.126	–0.094	0.074	0.076	0.454
SVF	0.126	0.037	–0.001	0.101	–0.082	0.000

Table 6. The average Delta for each scenario across environmental indicators (Source: Authors)

Indicator	CS1			CS2		
	H_norm	D_norm	O_norm	H_norm	D_norm	O_norm
WS -Summer	**1.000	*0.000	0.808	0.000	0.567	**1.000
WS -Winter	*0.000	**1.000	0.079	**1.000	*0.000	0.869
T _a -Summer	0.533	*0.000	**1.000	**1.000	*0.000	0.632
T _a -Winter	0.833	**1.000	*0.000	**1.000	0.870	*0.000
PMV- Summer	0.708	*0.000	**1.000	**1.000	*0.000	0.781
PMV- Winter	*0.000	0.935	**1.000	*0.000	0.007	**1.000
SVF	**1.000	0.298	*0.000	**1.000	*0.000	0.448
Average	0.582	0.462	0.555	0.714	0.206	0.676

* Worst Performance

** Best Performance

Table 7. Total mean for each scenario across both case studies (Source: Authors)

Indicator	CS1	CS2	Total Mean
H	0.582	0.714	0.648
O	0.555	0.676	0.616
D	0.462	0.206	0.334

in both cases were concentrated in **Zone C** (facing west), followed by **Zone A**, while the lowest values were recorded in **Zone B** (see Fig. 6). For the SVF, **Zone A** emerged as the most open to the sky, followed by **Zone B**, while **Zone C** recorded the minimum values in CS1. In CS2, **Zone A** remained the leader, but **Zone C** recorded the second-highest SVF values, and **Zone B** recorded the lowest SVF (most shaded). As shown in Fig. 6, PMV in CS1 ranged widely (5.85–8.43 in summer, –1.65–0.22 in winter). The highest values were concentrated in **Zones A** and **B**, and the lowest in **Zone C**. CS2 followed a similar pattern (5.69–8.31 in summer, –1.82–0.05 in winter), with **Zone A** having the widest PMV range. Regarding Ta, the highest readings in CS1 (up to 49.34°C in summer) were concentrated in the western part across **Zones B** and **C** during both seasons; **Zone A** recorded the lowest T_a values in winter. In CS2, the highest T_a values were concentrated in **Zone C**, followed by **Zone A** and then **Zone B**, in both summer and winter (Fig. 6).

Simulation of the proposed scenarios

Increasing building height scenario. Compared to the base case (Fig. 7), increasing building height led to higher WS in both case studies during summer, especially in **Zone B** and eastern **Zone C**, with the highest recorded WS reaching 3.29 m/s in CS1 and 4.03 m/s in CS2. However, WS decreased in winter for CS2 (dropping to 2.87 m/s), while it slightly increased to 3.71 m/s in CS1, especially in **Zones B** and **C**. SVF values decreased in both case studies, resulting in post-scenario ranges of 0.36–0.93 for CS2 (the greatest reduction) and 0.40–0.94 for

CS1. The decrease was concentrated in **Zones C** and **B** and at the edges of **Zone A**. Regarding PMV, although thermal comfort remained above the acceptable upper limits (+4), the values decreased in summer across both case studies (down to 5.58 in CS1 and 5.42 in CS2), especially in **Zones B** and **C**. In winter, the PMV increased slightly, with the rise concentrated in **Zones C** and **B**. As for Ta, the readings showed a very slight reduction (less than 0.3 °C) across all examined zones in both summer and winter (Fig. 7).

Changing the distance between buildings scenario. In this scenario, the distance between buildings was reduced in CS1 from 12 m to 10 m, and increased in CS2 from 8 m to 10 m. As a result, WS in CS1 decreased by 0.11–2.65 m/s in summer and by 0.09–2.58 m/s in winter when the distance between buildings was reduced, especially in **Zones B** and **A**; however, in **Zone C**, the WS gradient increased (Fig. 8). In CS2, a very slight increase in WS was observed across all zones, with values reaching 0.07–4.36 m/s in summer and 0.20–3.01 m/s in winter. According to Fig. 8, SVF in CS1 decreased to 0.32–0.86, concentrating in **Zones B** and **C**, while **Zone A** changed only at its edges. In CS2, SVF values increased to 0.50–0.93. The rise was concentrated in **Zone C**, and at the boundaries of **Zone A**. PMV values in CS1 decreased in summer to 5.77–8.38 across all Zones, and rose slightly in winter (–1.58–0.06). In CS2, the increase in distance led to higher PMV values (5.77–8.31 in summer, –1.86 to –0.10 in winter), especially in **Zones B** and **C**. **Zone A** showed no significant change. T_a decreased slightly in CS1 (summer: 47.42–48.11; winter: 15.66–16.54) across all zones. However, in CS2, a very slight increase was observed (summer: 47.48–49.34; winter: 15.65–16.59) across all zones.

Changing building orientation scenario. In this scenario, the orientation of both case studies was changed to the North-West. From the simulation results (Fig. 9), WS increased in CS1, with values reaching up to 2.5 m/s in summer and 2.7 m/s

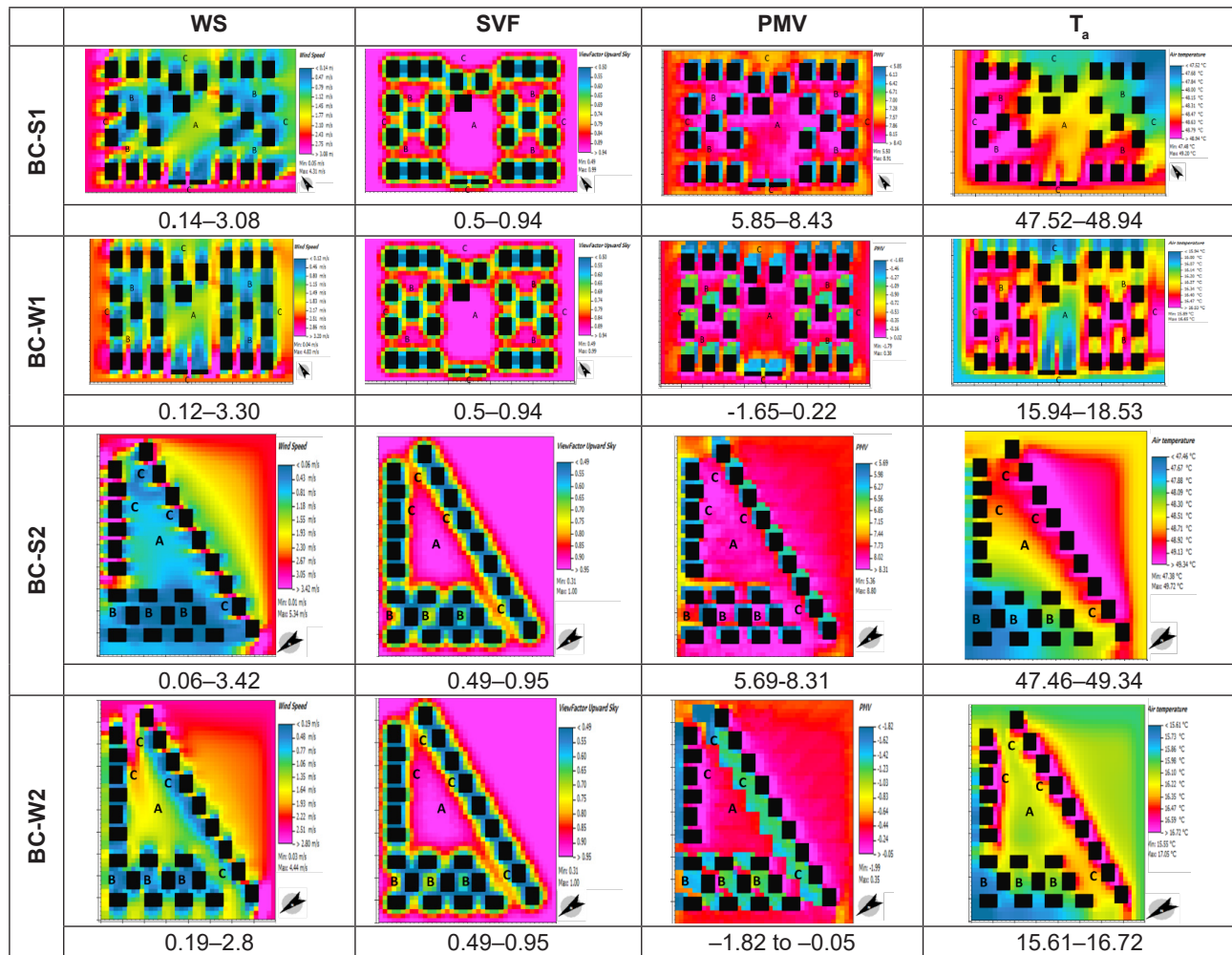


Fig. 6. Simulated maps of WS, SVF, PMV, and T_a generated by ENVI-met for the BC-CS1 and BC-CS2 at 15:00 (Source: Authors)

in winter, reflecting the spatial distribution between the eastern and western zones, while **Zone A** had no change. In CS2, the WS increased across **Zones A** and **C**, reaching the values up to 4.34 m/s in summer and 4.25 m/s in winter. SVF showed no change in either summer or winter in both case studies. Regarding PMV, the readings increased in summer (5.88–8.46 in CS1; 5.87–8.20 in CS2) and decreased in winter (CS1: -1.77 to -0.88; CS2: -1.94 to -0.08), reflecting similar spatial distributions in both case studies. T_a readings in CS1 rose slightly in summer (concentrated in eastern **Zone C**) and decreased in winter (observed in western **Zone C**), with changes of 0.3–0.4 °C. However, in CS2, T_a decreased slightly in summer and winter (by roughly 0.1–0.2 °C). This decrease was observed in **Zone B** (Fig. 9).

Discussion

Visual analysis of simulation maps for four environmental indicators in both case studies shows a close connection between urban design factors and climate performance. SVF is the main driver of temperature variation and thermal comfort. The

central plazas (**Zone A**) recorded the highest SVF values (CS1: 0.94; CS2: 0.95), making them focal points for solar radiation accumulation. In these areas, PMV reached very critical levels in summer (CS1: 7.86–8.4; CS2: 7.73–8.02) and varied seasonally. In winter, rapid heat loss due to night radiative cooling of the open sky made them the coldest zones. In contrast, building entrances (**Zone C**) and interbuilding spaces (**Zone B**) provide 'mass shading' which successfully reduces thermal stress. The WS enhanced natural ventilation (3.42 m/s). However, the impact of wind on T_a depends on the source of the air mass. For instance, in Basra's climate, where hot, dry north-westerly winds are prevalent, increasing WS may raise T_a through convection before achieving physiological cooling. These findings show that outdoor open spaces in both case studies experience sharp thermal fluctuations and high SVF. This highlights the need to modify the schematic to improve environmental indicators and ventilation. Therefore, the current study proposes scenarios for three urban design factors—height, distance between buildings, and

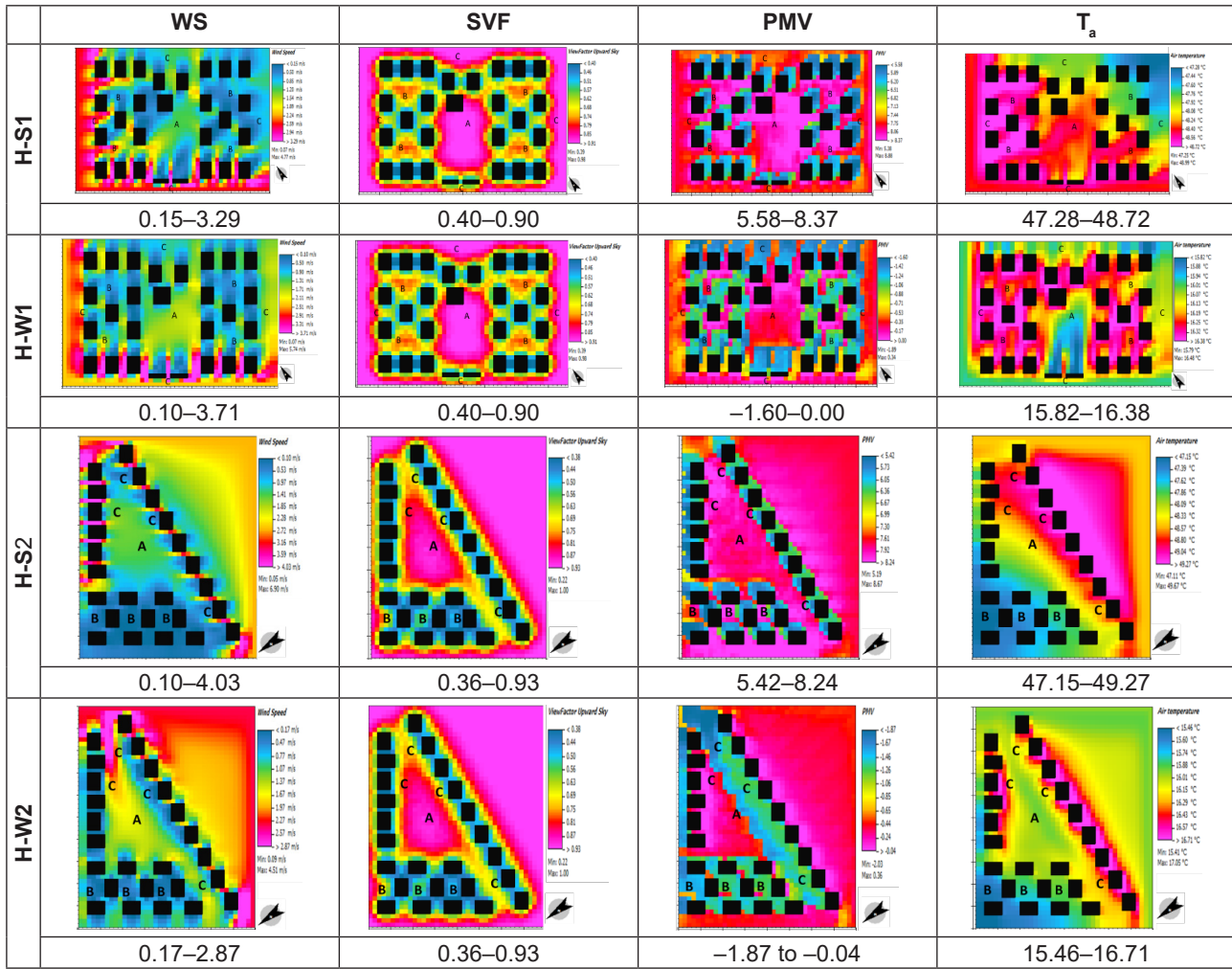


Fig. 7. Simulated maps of WS, SVF, PMV, and T_a generated by ENVI-met of the height scenario of CS1 and CS2 at 15:00 in summer and winter (Source: Authors)

building orientation — to determine which has the most positive effect on ventilation, aiming to generalise findings to similar spaces.

The statistical analysis, using the normalised Delta values as described in section 4.1, which adjusts differences to a common scale to allow comparison, was used to evaluate improvements in environmental indicators and to provide a clear ranking of urban design factors influencing ventilation. The most influential factor was building height, followed by building orientation, and then distance between buildings. This ranking was consistent in all case studies, as shown in Table 7. The statistical analysis for the building height factor indicated an improvement of 0.648. This finding aligned with visual analysis results, which demonstrated marked improvements in environmental indicators for both study cases. It was observed that vertical expansion led to an increase in air pressure at the building entrances (**Zone C**), in the interbuilding spaces (**Zone B**), and at the edges of the central plaza (**Zone A**). Thus, air velocities increased during the

summer season. This dynamic reversed in winter, which led to reduced thermal stress and improved physiological cooling in hot, humid conditions. This finding highlighted the influence of building height on environmental performance, supporting the findings of Lin et al. (2026) in a comparable urban context. It also aligns with the findings of Ragheb et al. (2024) study in Egypt's hot-arid climate, suggesting that the positive effect of building height on ventilation and thermal comfort may be observed across different hot-climate types. This scenario also supported the buildings' role as thermal chimneys that draw hot air upwards, in line with Palusci et al.'s (2022) study.

The visual map analysis also revealed decreased SVF values in both summer and winter, leading to increased mutual shading at interbuilding spaces (**Zone B**), building entrances (**Zone C**), and the central plaza edges (**Zone A**). This shading contributed to reducing the levels of solar radiation, which reduced the effect of heat islands by forming cool air pockets at entrances (**Zone C**), and slightly decreased PMV in summer while increasing it in

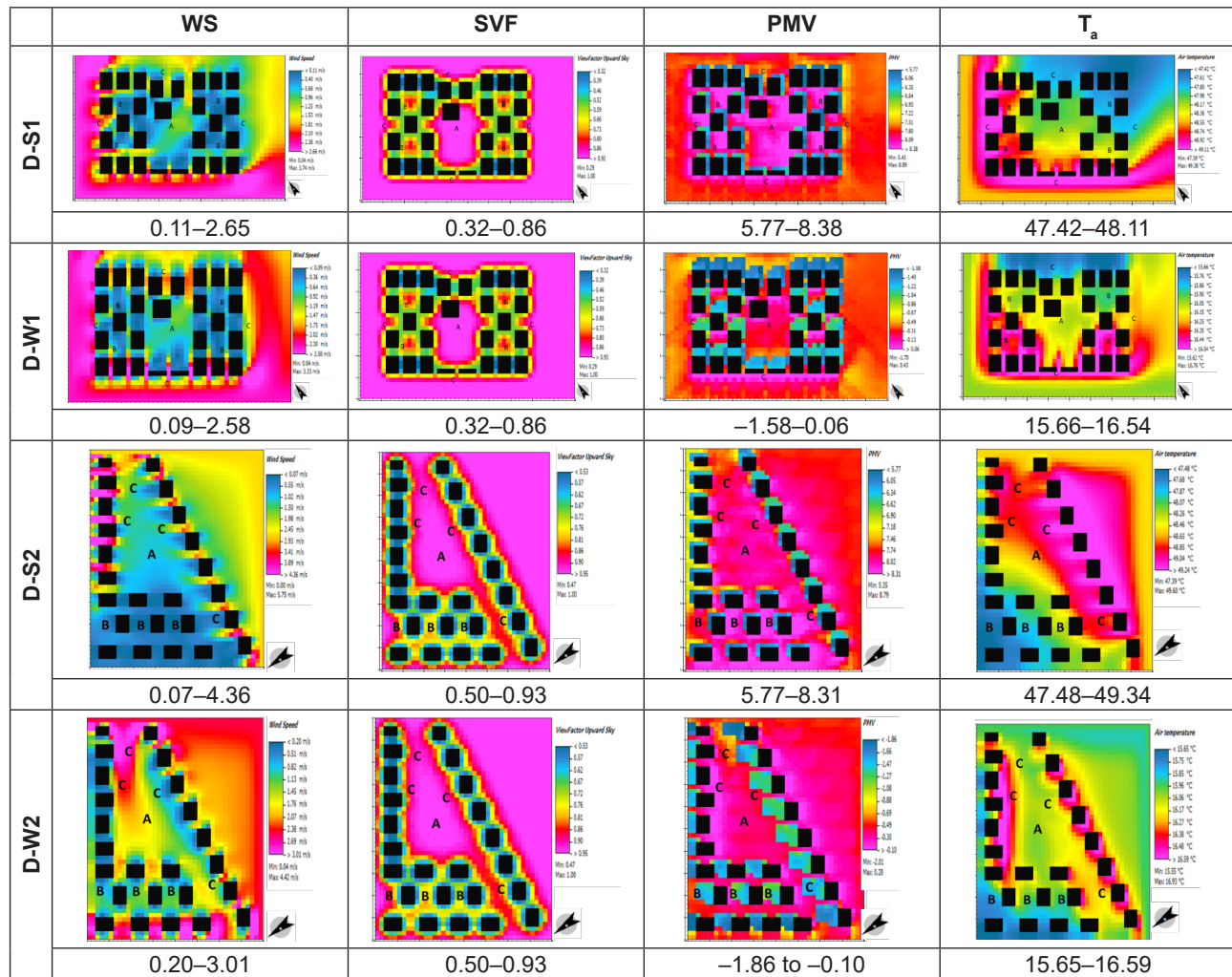


Fig. 8. Simulated maps of WS, SVF, PMV, and T_a generated by ENVI-met of the distance scenario for CS1 and CS2 at 15:00 in summer and winter (Source: Authors)

winter, thereby reducing heat loss. These results align with Zheng et al. (2019), who found that taller buildings yield lower surface temperatures due to increased shading. This can explain reduced summer air temperatures in CS2 zones: interbuilding spaces (**Zone B**) and at building entrances (**Zone C**) compared with those in CS1. This may be because building height diversity in CS2 helps lower air temperatures compared to designs with less contrast in CS1, as found in Salameh et al.'s (2023) study. This finding is consistent with those of Pouri et al. (2025), who demonstrated that modifying aspect ratios to control SVF can moderate surface heat loss and enhance passive heat storage.

Statistical analysis showed that building orientation ranked second, with an improvement margin of 0.616. This result matches the visual analysis, which showed that orientation change improved WS in CS1 in both summer and winter, with improvement at building entrances (**Zone C**) and the central plaza (**Zone A**). In CS2, improvements were observed only in winter and were limited to

the building entrances (**Zone C**), attributable to their position relative to prevailing winds, and also occurred in interbuilding spaces (**Zone B**) and at the boundaries of the central plaza (**Zone A**). These results are consistent with those of Mahmoud and Ghanem (2019), who studied the role of orientation in cross ventilation. The visual analysis also showed that the stable SVF value across seasons in both case studies indicates that orientation alone does not affect thermal radiation rates, unless combined with changes in block shape or open-space configuration. Regarding thermal effects, values of both T_a and PMV increased in summer in both case studies: the increase was widespread in CS1 and concentrated in the central plaza (**Zone A**) in CS2, due to heat gain from dry, hot winds and altered facade solar exposure angles. These results are in line with those of Mahmoud and Ghanem (2019), confirming the importance of orientation for thermal performance. The observed site-specific variation in surface heat levels supports the argument of Derakhshan and Karimimoshaver (2026) that orientation effects

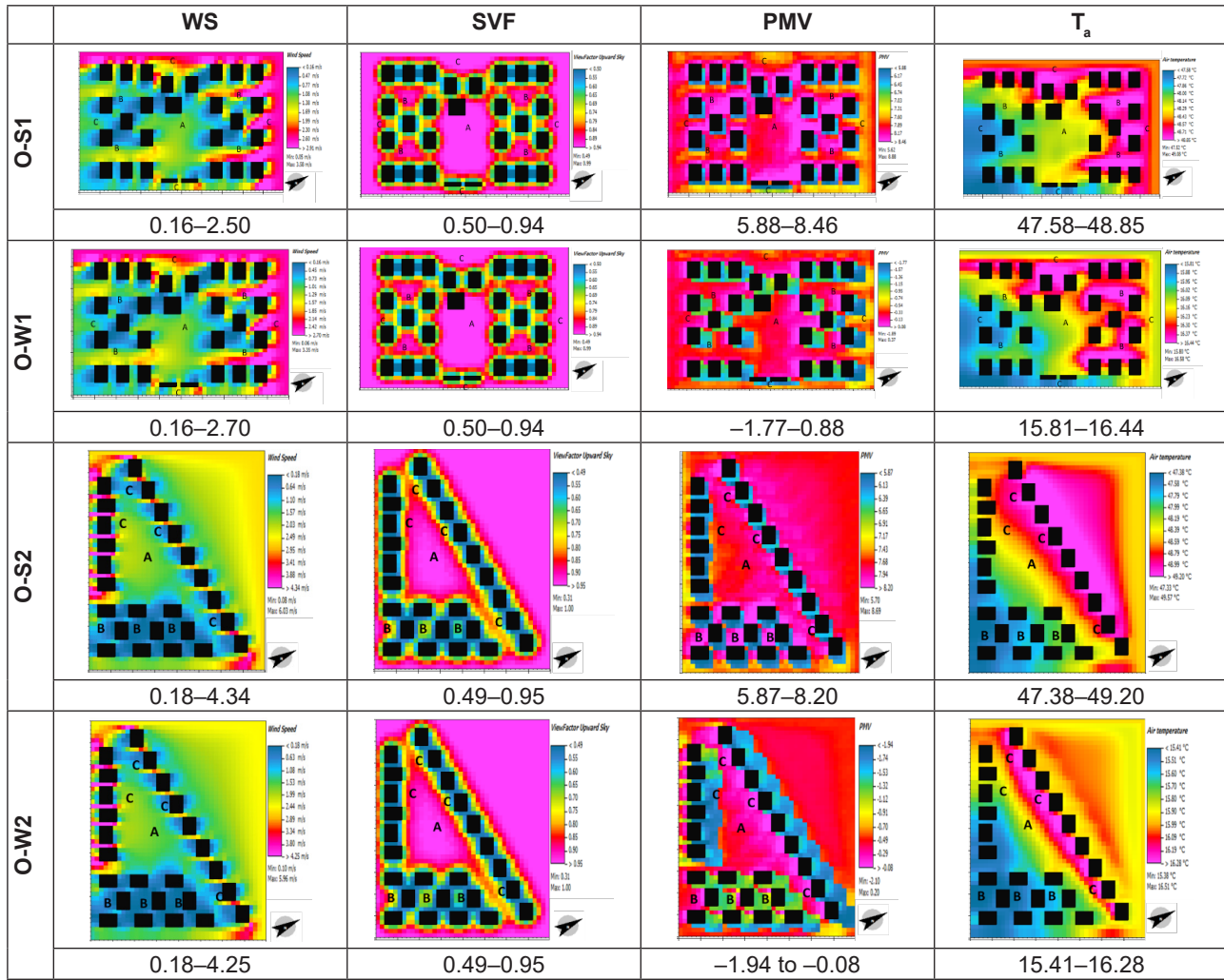


Fig. 9. Simulated maps of WS, SVF, PMV, and T_a generated by ENVI-met of the orientation scenario for CS1 and CS2 at 15:00 in summer and winter (Source: Authors)

cannot be generalised. It is important to highlight the role of the north-west orientation in improving ventilation in both case studies (Abdelhafez et al., 2022). This aspect corroborates the findings of Lin et al. (2026), whose research showed that orientation promotes an equitable distribution of ventilation. However, the promotion of thermal comfort through orientation remained subject to the combined effects of WS and radiation, as they related to orientation and urban morphology in both case studies. Therefore, urban designers should employ an integrated approach that balances ventilation and solar radiation in hot, humid climates.

The results showed that changes in the distance between buildings ranked third in optimisation efficiency, with a difference of 0.334. A visual analysis further revealed an inverse relationship between “urban breathing” and thermal radiation protection. Mass convergence in CS1 caused air stagnation in interbuilding spaces (**Zone B**) and at building entrances (**Zone C**). This effectively lowered the SVF value, reduced thermal stress, and improved

PMV and T_a during summer daylight hours. This is supported by the findings of Mahmoud and Ghanem (2019) and Fan et al. (2024) in the same section of their studies, which recommended prioritising shading in hot climates. In contrast, greater distances between buildings in CS2 promoted airflow, aligning with the urban breathing concept (Juan et al., 2021). This also confirms the CFD-based findings of Ghalam et al. (2021) and the numerical simulations of Ayo and Mohd-Ghazali (2024), who revealed the effectiveness of the distance between buildings on ventilation performance. However, the greater distances between buildings could increase annual solar radiation and T_a, and in turn, increase PMV and SVF. Accordingly, a design balance between ventilation and heat protection is required. Thus, semi-closed layouts are more suitable for hot daytime conditions, while sparse layouts cool more efficiently at night (Lam and Hang, 2017).

Conclusion

The research examined the impact of three urban design factors (building heights, the distance

between buildings, and building orientation) on improving ventilation in outdoor open spaces between multi-storey residential buildings in the hot, humid climate of Basra city. This aim was achieved by applying a case study approach along with statistical and visual analysis. The study simulated 16 models, four of which represented the base case for two case studies in summer and winter, and 12 were proposed models under three scenarios: increment height of buildings (H-scenario), changing the distance between buildings (D-scenario) or changing orientation (O-scenario). The statistical results, supported by visual analysis, indicated that the most influential factor in improving the environmental indicators examined in the two case studies was building height, followed by orientation, and then distance between buildings.

1. Building height was the most effective factor for achieving natural ventilation in hot, humid climates such as Basra city, both in summer and winter, because increasing building height transforms the urban fabric from a radiant receiver to a mutual shading system. This reduced winter heat loss by lowering cold wind speeds and raising PMV values towards the winter comfort zone, thereby achieving "improved seasonal thermal performance".

2. Orientation took second place in improving ventilation. Despite its importance in breaking the state of "air stagnation" and increasing wind speed, the trade-off was a slight increase in T_a due to convective heat gain from hot winds, but it did not change the SVF values. This means that the area exposed to sunlight was not changed in summer and winter. Therefore, to achieve maximum ventilation efficiency in Basra city, effective solutions and treatments must be identified for both seasons to support environmental sustainability. A pattern

of vertical blocks oriented north-west should be implemented to meet radiation protection standards and the minimum urban breathing requirements.

3. The distance between buildings factor revealed a design trade-off requiring a balance between ventilation and shading. Increasing the distance between buildings benefited urban ventilation, but it also made the spaces more exposed to solar radiation and to higher PMV values. Accordingly, the study suggested that vertical stacking method for mutual shading can be the best design strategy for Basra city. This strategy can reduce thermal stress and improve the physiological comfort of pedestrians when temperatures exceed 48°C.

4. There is a need to identify environmental treatments to improve the currently studied outdoor open spaces and similar ones that are exposed to sunlight and experience high PMV values. It is recommended to use artificial or plant shading elements in courtyards with dimensions greater than 10–12 meters to compensate for the lack of self-shading by buildings.

5. This study offers an analytical framework for similar urban spaces, provided that it aligns with the city of Basra's urban and climatic context, characterised by high summer temperatures (>48°C), high humidity, the dominance of north-westerly winds, and a medium to high-density urban fabric of multi-storey residential buildings. It is recommended that the same methodology be re-applied in other climate contexts to test the extent to which the results can be generalised more widely.

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ВЛИЯНИЕ ГОРОДСКОЙ ЗАСТРОЙКИ НА ВЕНТИЛЯЦИЮ В УСЛОВИЯХ ЖАРКОГО И ВЛАЖНОГО КЛИМАТА: МНОГОЭТАЖНЫЕ ЗДАНИЯ В БАСРЕ

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Аннотация

Цель исследования заключалась в выявлении наиболее значимых факторов градостроительного проектирования, способствующих улучшению вентиляции открытых пространств в многоэтажных жилых комплексах Басры, климат которой характеризуется высокой температурой и влажностью. **Методы:** на примере жилого комплекса «Аль-Амаль» было проведено моделирование в программе ENVI-met (версия 5.9) для 16 вариантов двух участков территории в летний и зимний периоды. Четыре модели отражали существующие условия, а 12 других представляли собой сценарии с варьированием высоты зданий, расстояния между ними и их ориентации; оценка проводилась по таким показателям, как температура воздуха (T_a), скорость ветра (WS), коэффициент видимости неба (SVF) и прогнозируемая средняя оценка теплового комфорта (PMV). **Результаты** показали, что высота зданий является наиболее значимым фактором для улучшения вентиляции и обеспечения эффекта самозатенения; за ней следует ориентация зданий по оси северо-запад. Расстояние между зданиями оказалось наименее значимым фактором из-за необходимости искать компромисс между обеспечением аэрации («дыханием» городской среды) и увеличением уровня инсоляции. В исследовании рекомендуется использовать компактные высотные блоки, ориентированные на северо-запад, а также применять элементы озеленения или искусственные навесы для компенсации снижения эффекта самозатенения и стимулирования социального взаимодействия.

Ключевые слова: факторы градостроительного проектирования; вентиляция; многоэтажные жилые здания; тепловой комфорт; ENVI-met; Басра.