Civil Engineering and Architecture 14(2): 810-839, 2026 http://www.hrpub.org
DOI: 10.13189/cea.2026.140212

Impact of Urban Morphology on Ventilation in Sustainable High-Rise Housing in Mediterranean Climates: A Case Study of Bashayer Al-Khair, Alexandria

Menna T. Elekiaby[1,*], Mohamed M. Eldabosy[2], Mohamed M. Shawky Abou Leila[2]

[1]Faculty of Engineering, Damietta University, Egypt
[2]Department of Architecture Engineering, Faculty of Engineering, Mansoura University, Egypt

Received July 4, 2025; Revised December 10, 2025; Accepted January 20, 2026

Cite This Paper in the Following Citation Styles

(a): *[1] Menna T. Elekiaby, Mohamed M. Eldabosy, Mohamed M. Shawky Abou Leila , "Impact of Urban Morphology on Ventilation in Sustainable High-Rise Housing in Mediterranean Climates: A Case Study of Bashayer Al-Khair, Alexandria," Civil Engineering and Architecture, Vol. 14, No. 2, pp. 810 - 839, 2026. DOI: 10.13189/cea.2026.140212.*

(b): *Menna T. Elekiaby, Mohamed M. Eldabosy, Mohamed M. Shawky Abou Leila (2026). Impact of Urban Morphology on Ventilation in Sustainable High-Rise Housing in Mediterranean Climates: A Case Study of Bashayer Al-Khair, Alexandria. Civil Engineering and Architecture, 14(2), 810 - 839. DOI: 10.13189/cea.2026.140212.*

Abstract Egypt is in the process of implementing the International Agenda 2030. In September 2015, the United Nations adopted this framework and established 17 Sustainable Development Goals (SDGs) to be achieved between 2016 and 2030. Among these, priority is given to creating towns and human settlements that are inclusive, safe, resilient, and sustainable. This paper examines various urban form parameters to regulate outdoor thermal and wind comfort in the Bashayer Al-Khair Housing Project, Alexandria. Microclimatic conditions in specific districts were analysed experimentally using ENVI-met 4.0 software. Three neighbourhood geometries (rectangular courtyard, linear, and square courtyard) with different densities were simulated and compared during the summer of 2023. Results show that the square courtyard typology provides the most favourable microclimatic conditions. Increasing the height-to-width (H/W) ratio from 1.5 to 4.5 reduces average air temperature by approximately 3-4 ℃, increases wind speed from 2.25 to 3.83 m/s, and moderately raises relative humidity from 77% to 82%, highlighting the benefits of taller and narrower urban forms for improved ventilation and thermal comfort. The most effective configuration is the square courtyard with a floor area ratio (FAR) of 7.66. Based on these findings, the study explicitly recommends adopting the square courtyard urban form in future housing projects in Egypt, as it enhances outdoor thermal comfort while supporting sustainable urban development goals.

Keywords Affordable Housing, Environmental Performance, Urban Block Typology, High-Rise Buildings, ENVI-met Simulation

1. Introduction

The creation of comfortable outdoor thermal environments in urban spaces has become an essential research issue in building science as part of the effort to address global climate change. The development of residential spaces that are high-rise has boomed due to Egypt's rapid development and increasing density of population [1]. Outdoor thermal comfort (OTC) is affected by the speed of wind, which is one of the main factors. Human thermal perception is significantly influenced by the role played by wind in heat dissipation, evaporative cooling, and pollutant dispersion. In warm weather, increased wind speed can enhance cooling effects, reduce thermal stress, and improve comfort levels in outdoor spaces. In colder climates, excessive wind exposure may lead to discomfort; therefore, it is essential to regulate it carefully [2].

The global housing crisis is being addressed by sustainable development of affordable housing, which is a crucial element in minimizing environmental impact and fostering resilient communities [3]. Wind flow to enhance outdoor thermal comfort can be achieved through several urban design strategies, such as building orientation, street geometry, vegetation, and open spaces [4]. The impact of different urban layouts on wind behaviour has been extensively studied using CFD simulations and field measurements [5].

1.1. Literature

Since 2010, an increasing number of studies have examined the influence of urban morphology—particularly the height-to-width ratio (H/W), block orientation, and inter-building spacing—on outdoor thermal comfort (OTC). Recent findings highlight that the H/W ratio is a critical determinant of microclimatic conditions. For example, one study [6] demonstrated that canyon aspect ratio and orientation strongly affect OTC, with higher ratios providing shading but limiting wind penetration. Similarly, a long-term bioclimatic analysis in Campinas, Brazil, showed that both H/W ratio and street orientation shape thermal conditions in urban canyons [7].

More recent investigations emphasize the synergistic effects between urban geometry and other design elements. For instance, deeper canyons (higher H/W) not only reduce solar exposure but also enhance airflow, thereby lowering ambient air temperature [8]. A field-based ENVI-met simulation in Taiyuan, China, further confirmed that both canyon aspect ratio and tree spacing substantially improve pedestrian comfort by reducing mean radiant temperature and Physiological Equivalent Temperature (PET) values [9].

In Mediterranean contexts, earlier contributions have been expanded by more recent studies. Research in Irbid, Jordan, revealed that optimized canyon aspect ratios (1.5–4) and adequate inter-block spacing improve Universal Thermal Climate Index (UTCI) values while simultaneously reducing energy consumption [10]. Likewise, comparative research on residential complexes in Tunis demonstrated that block formation and morphology directly influence solar gains and thermal efficiency in warm Mediterranean climates [11].

Building on this body of knowledge, the present study advances the discussion by analysing the combined influence of H/W ratio, block configuration, and inter-block voids on OTC in Alexandria's Bashayer Al-Khair housing project. The results confirm established patterns—such as the trade-off between shading and ventilation—while also underscoring the particular role of humidity, a factor that remains underexplored in Mediterranean high-rise contexts.

- **Ventilation, Wind Speed, Temperature, and Humidity in Outdoor Environments**

Ventilation, defined as the exchange of air between a space and its surroundings, is essential for regulating outdoor microclimates, particularly in dense urban environments where the built form constrains airflow [12]. The efficiency of ventilation is influenced by several factors, including urban geometry, vegetation, and building density, all of which shape wind flow and its cooling potential.

Wind speed, commonly measured in meters per second (m/s), plays a crucial role in outdoor thermal comfort. Higher wind speeds generally enhance evaporative cooling, disperse excess heat, and reduce perceived thermal stress, especially in hot and humid climates [13]. Conversely, low wind speeds may intensify discomfort in such contexts.

Air temperature and humidity are equally important determinants of thermal perception. Elevated air temperatures increase sensible heat stress, while high humidity limits the effectiveness of evaporative cooling. Together with wind conditions, these variables determine the Physiological Equivalent Temperature (PET) and other comfort indices, thus directly affecting outdoor thermal comfort levels [14].

- **Density Variable**

The floor area that is usable for each unit of site area on a particular site is indicated by Plot Ratio or Floor Area Ratio, which measures constructed density in this research. To increase the density of constructed structures, one of the most effective methods is to increase building height [15]. Environmental performance and outdoor urban comfort are directly affected by FAR, which includes factors such as thermal comfort, wind flow, and access to natural light [16]. Dense building configurations with high FAR values can lead to increased surface coverage and a lack of green and open spaces that help reduce heat stress, thereby influencing OTC and PET levels.

- **Aspect Ratio**

Thermal comfort–based urban planning relies heavily on the aspect ratio, the proportion between the height of a building and the width of the street. The aspect ratio (H/W) is calculated by dividing the average building height (H) by the street width (W) [17]. Deep street canyons with an increased aspect ratio decrease solar exposure and air temperature. Shallow and deep canyons are indicated by H/W ratios below 0.5 and around 2, respectively [18]. Architectural and urban studies rely heavily on this parameter as it affects environmental factors such as ventilation, OTC, and daylight penetration. High aspect ratios, which refer to taller buildings with narrower streets, can be used to effectively channel wind and improve PET values [19].

- **Outdoor Thermal Comfort (OTC)**

Outdoor Thermal Comfort (OTC) is a key concept in assessing the liveability of urban spaces, as it reflects the combined impact of microclimatic factors such as air temperature, humidity, wind speed, and solar radiation on human well-being. Several studies have highlighted the role of urban morphology—including density, aspect ratio, and block configuration—in shaping OTC in different climates [20]. In Mediterranean contexts, where hot summers and high humidity levels prevail, OTC is particularly critical for promoting sustainable housing design and reducing reliance on mechanical cooling. Therefore, OTC provides a direct link between morphological parameters and the methodological framework applied in this study.

- **Physiological Equivalent Temperature (PET)**

The Physiological Equivalent Temperature (PET) index is one of the most widely used indicators for evaluating outdoor thermal environments. PET integrates climatic variables (air temperature, mean radiant temperature, humidity, and wind speed) with human energy balance models to estimate thermal stress as perceived by individuals [21]. Its advantage lies in translating complex thermal interactions into an equivalent temperature that is easily understood and comparable across studies. Previous research has employed PET extensively to assess thermal comfort in street canyons, public open spaces, and residential neighbourhoods [22]. By using PET in this paper, the results can be directly compared with existing literature while ensuring consistency in the evaluation of OTC under Mediterranean climatic conditions.

- **Affordable Housing**

Affordable housing programs aim to provide shelter for low-income groups but often fail to meet the severe housing deficits in developing countries, where substandard housing still affects over one billion people. The UN-CESCR highlights adequate housing as a fundamental right, stressing affordability and liveability [23].

In rapidly urbanizing regions, these projects usually adopt compact urban forms with densities of 200–400 persons/ha. Yet, high densities combined with poor orientation and limited inter-block spacing restrict ventilation and solar access, leading to overheating and reduced outdoor thermal comfort (OTC). Studies in Mediterranean contexts show that street canyons with H/W ratios of 0.5–1.5 and blocks oriented to prevailing winds can reduce peak temperatures by 2–3 ℃ [24].

In Egypt, projects such as Bashayer Al-Khair demonstrate how variations in density and block spacing affect OTC, while the Housing for All Egyptians program in New October City (≈90,000 units) incorporates infrastructure and green spaces to counter high-density effects. Similarly, research on Sakan Masr confirms that orientation, shading, and density adjustments can lower cooling loads and improve thermal performance.

These examples underline the importance of embedding morphological parameters (density, orientation, H/W ratios, and inter-block spacing) into affordable housing design to optimize land use, reduce energy demand, and enhance liability in hot Mediterranean climates.

1.2. Problem Definition

To address the housing problem and accommodate the large increase in population, the Egyptian administration is attempting to carry out municipal planning and residential development. In the last five years, the Affordable Housing Projects have been regarded as the most significant national project for low-income people. Ensuring comfortable spaces for human activities, encouraging residents to engage in outdoor activities, and mitigating heat-related discomfort on the facades of the buildings require prioritizing outdoor heat management in such developments, and mitigating heat load on the structures' facades.

1.3. Objective and Research Gap

The aim of this study is to investigate strategies for enhancing Outdoor Thermal Comfort (OTC) in a warm-humid city, Alexandria, Egypt, through urban configuration design. The main focus of the research is on building typology and spatial arrangement, with the goal of creating healthy, livable urban environments that provide comfort and a sense of relaxation, particularly in affordable housing projects.

Specifically, the study seeks to:

- Assess urban thermal comfort in affordable housing projects in Egypt to determine the extent to which OTC has been achieved and identify ways to improve it in future housing designs.
- Illustrate the relationship between the spatial configuration of high-rise residential buildings and outdoor thermal comfort.
- Examine the influence of wind speed, temperature, and humidity on OTC and investigate how urban design modifications can enhance airflow and create thermally comfortable outdoor spaces.
- Evaluate the effects of urban density and inter-block spacing on microclimatic conditions, including shading, ventilation, and thermal perception.
- Compare different high-rise residential layouts (square, linear, rectangular) to identify optimal configurations that maximize outdoor comfort while maintaining high-density land use.
- Provide practical recommendations for improving the design of affordable housing projects in Mediterranean climates to enhance thermal comfort and sustainability.

The study utilizes ENVI-met simulation software to propose optimal urban arrangements. By analysing different configurations of high-rise residential complexes, the research evaluates the proportion of outdoor space and the floor area ratio relative to building volume. Material properties of roads, pavements, and roofs are also examined to assess their impact on temperature variations and climatic conditions [25].

2. Materials and Methods

The goal of this research is to investigate the best Urban Form for affordable housing in Alexandria, Egypt. The investigation of effective design factors for building geometry in outdoor spaces is the subject of this research. Creating the methodology for a case study that is implemented in phases (Figure 1). To evaluate different configurations and designed scenarios, the ENVI-MET tool and Physiological Equivalent Temperature index are utilized as part of this methodological workflow.

- Phase one: Collecting information on the Bashayer Al-Khair Housing Project that is situated in Alexandria, the climate consultant tool was employed to create climatic data for data analysis and supplement the weather data that already exists.
- Phase two: Urban microclimate modeling using ENVI-met, with data visualization via LEONARDO, focusing on boundary layer simulation. Comparing multiple states against each other.
- Phase three: Using a simulated building typology to compare different scenarios and achieve the best one (Square courtyard, rectangular courtyard, linear). Comparing various scenarios to find the optimal one using simulated results: The ratio of H to W (1.5, 2.5, 3.5, 4.5).
- Phase four: Discussing the most efficient microclimate scenario.

The 15th of August, is one of the hottest days of the summer. The objective of this selection is to observe the effects of alternative urban forms on the thermal environment sensation of users. The simulation at 1:00 p.m. on August 15, the ENVI-met model was run for one hour. Accordingly, the results presented in this study reflect the conditions observed at 2:00 p.m. This is referred to as the thermal peak time. In accordance with the same scientific studies.

The Bashayer Al-Khair project in Alexandria utilizes construction materials, including bricks of specific thickness for buildings, asphalt for streets, and concrete or tiled surfaces for sidewalks.

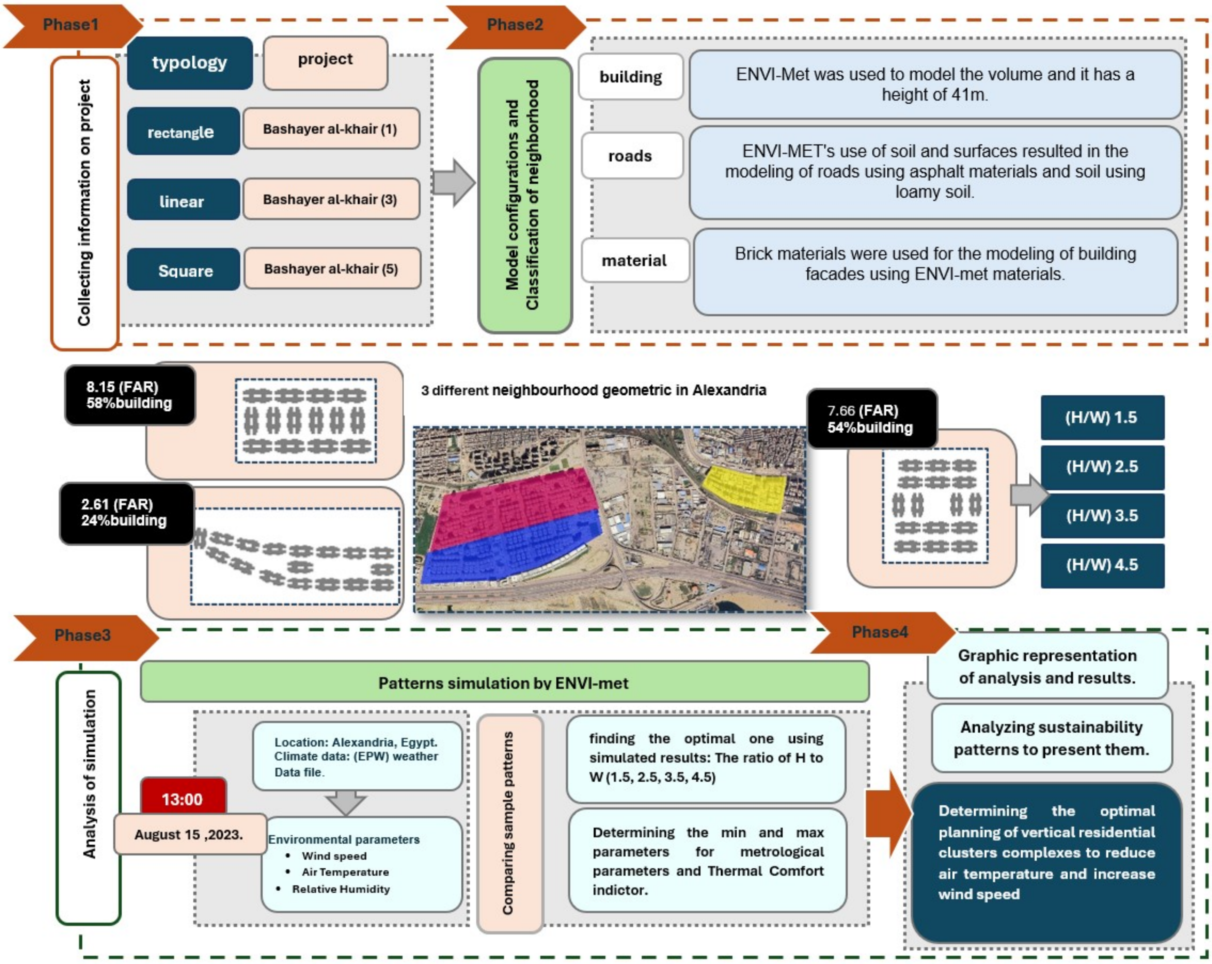


Figure 1. The flowchart for research methodology showing the sequence of steps required to investigate the best urban layout for affordable housing by the author

2.1. Climate Conditions

The mean daily maximum temperature was recorded at 25 ° to 31 ° in summer when the Climate Consultant Software was utilized to create the existing weather data, based on data from the EPW file (Figure 2). Alexandria has a mean Wind Speed of 4.7 m/sec, which is the prevailing Airflow direction (Figure 3). Spring brings the phenomenon of Khamasin, where the south-east winds cross the country. Carrying a lot of dust and sand from the desert, the wettest month is January, and the dryest month on average is August. Alexandria is a city located on the coast and extends approximately a 32-kilometer stretch of Mediterranean coastline. Relative humidity is currently at a maximum level, with approximately 70% within the span of 55% to 80%.

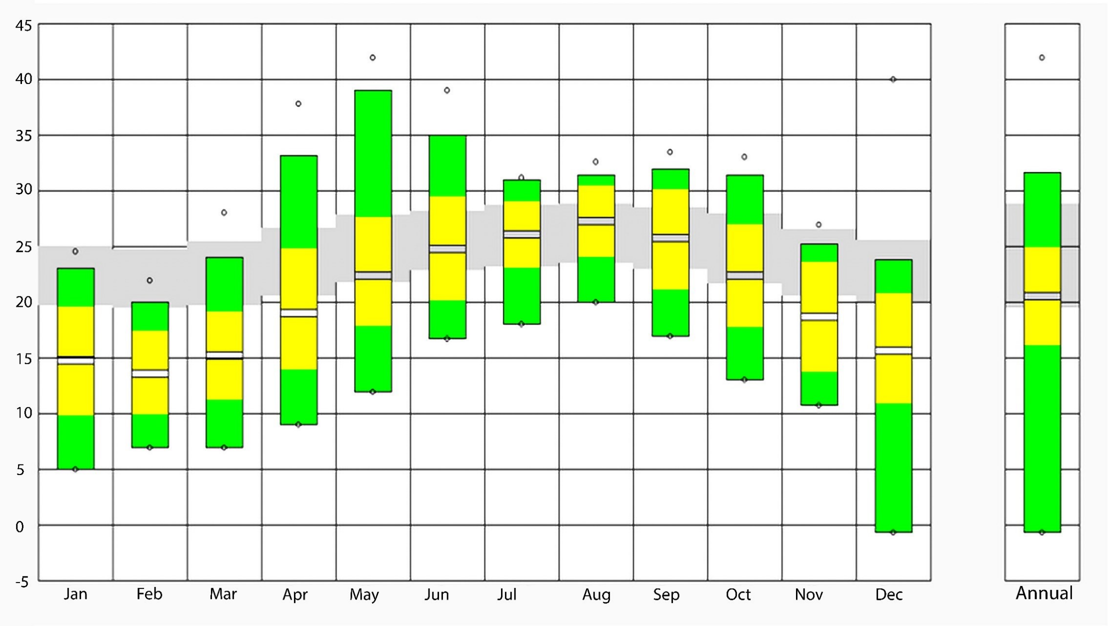


Figure 2. Monthly Temperature Range chart for Alexandria experiences a Mediterranean climate [26]

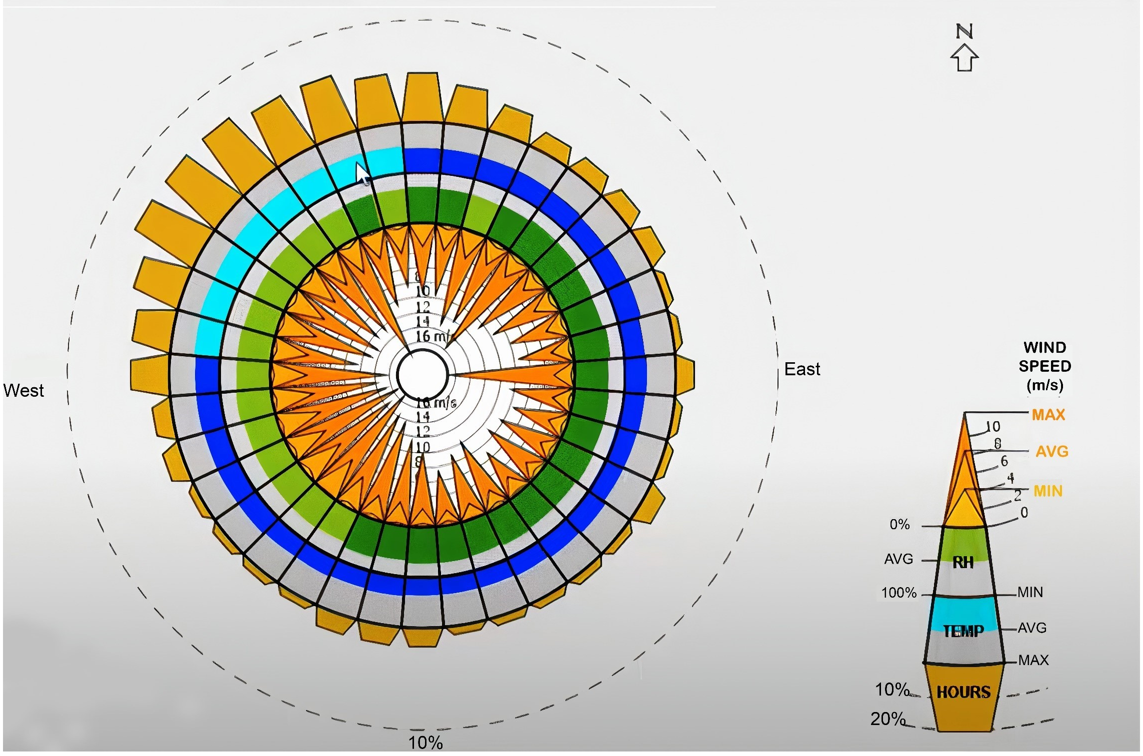


Figure 3. Wind Rose of Hissar chart for Alexandria showing the distribution of wind directions and speeds [26]

2.2. Limitations

This study focused on Alexandria as a representative Mediterranean city, with the Bashayer Al-Khair affordable housing projects serving as the case study for low-income housing initiatives. While this approach provides a valuable example that could potentially be replicated in other Mediterranean contexts, it is subject to certain limitations:

- Seasonal coverage: The analysis was restricted to the summer season, when Egypt experiences the highest temperature levels, and therefore does not capture seasonal variations in outdoor thermal comfort (OTC).
- Methodological approach: Instead of conducting extensive field measurements, the study relied on theoretical simulations using ENVI-met software. Although ENVI-met allows testing multiple scenarios—such as adjusting building ratios or exploring alternative block configurations to improve thermal comfort—it cannot fully replace real-world measurements.
- Climatic parameters: While the software provides detailed outputs on climatic parameters, including wind speed, air temperature, and humidity, the results remain model-dependent and may be influenced by the assumptions and input data used.
- Scope of influencing factors: Outdoor thermal comfort is affected by multiple factors, including height-to-width ratio (H/W) of urban canyons, building materials, block orientation, and vegetation. However, this study focuses specifically on the effects of urban density and H/W ratio as primary determinants. Other factors were not considered and could be addressed in future research to provide a more comprehensive assessment of thermal comfort in social housing projects.

2.3. Site Selection

This research examines the effect of developed informal settlements with high-rise buildings and urban development on Urban Heat Island (UHI) reduction. Accordingly, the Bashayer Al-Khair Housing Projects (phases 1, 3, and 5) were selected as case study areas due to the following:

- These neighborhoods serve as real-life examples of developed informal settlements catering to low-income families.
- They represent a variety of urban typologies, including both compact and open layouts, allowing for comparison of spatial configurations.
- The sites include areas of high and low density with high-rise buildings, providing an opportunity to examine the influence of density on outdoor thermal comfort (see Table 1 for different density values for each phase).
- Different architectural and block layouts can be compared across the phases to understand the effect on microclimatic conditions.
- Site boundaries, street widths, and block arrangements are clearly defined and documented, and the site layout is presented in Figure 4, highlighting the spatial organization and density distribution.

2.4. Simulations Tool

The complexity of urban climate makes numerical simulation a highly applicable methodology for outdoor thermal comfort investigation [27]. Field studies are not as preferable due to the wide range of morphological variables. Numerous studies have employed computational simulations [28]. 3D microclimate simulation model is utilized to analyze three design scenarios using computational simulation of microclimatic conditions in this research. ENVI-Met is a tool that uses microclimate to provide Exact values for the parameters Dry-Bulb Temperature (℃), Radiant Temperature (℃), Humidity Ratio (g/kg), Wind Speed (m/s), and Solar Energy, which serves to assess Universal Thermal Climate Index (UTCI), all of which serve as indicators of human comfort in outdoor spaces. Envi-met has proved to be a reliable tool that gives precise information in close proximity to the actual weather conditions [29], especially for summer calculations.

Furthermore, the study makes use of the complete Forcing Method Applied Universally (humidity, solar radiation, wind, and temperature), furthering the accuracy of the model [30]. Extracting these effective meteorological factors was done using the ENVI-met program V 4.4.1 in this study. The case study areas were simulated through alternative scenarios using ENVI-MET software to take into account the blocks, landscape, and vegetation. The preparation files are necessary to define the workspace through two main folders in Envi-met software. Additionally, it must generate two main Input data: Data File (.INX), a definition of the simulation area, which encompasses plants, buildings, soil, and sources; and the additional file is the configuration file (.CF).

Table 1. Details of the three sites (the whole urban area of the site, the ground level area of all the buildings on the site, the site construction percentage, floor area ratio, the site construction density ratio and the site population density [32]

Site	total urban area (m^2)	the ground floor area (m^2)	site construction percentage	Floor area ratio	site population density ratio (p/m^2)
Bashayer Al-khair (1)	51.743	12.240	0.237	2.61	0.16
Bashayer Al-khair (3)	247.000	144.000	0.582	8.15	0.21
Bashayer Al-khair (5)	378.000	207.360	0.547	7.66	0.20

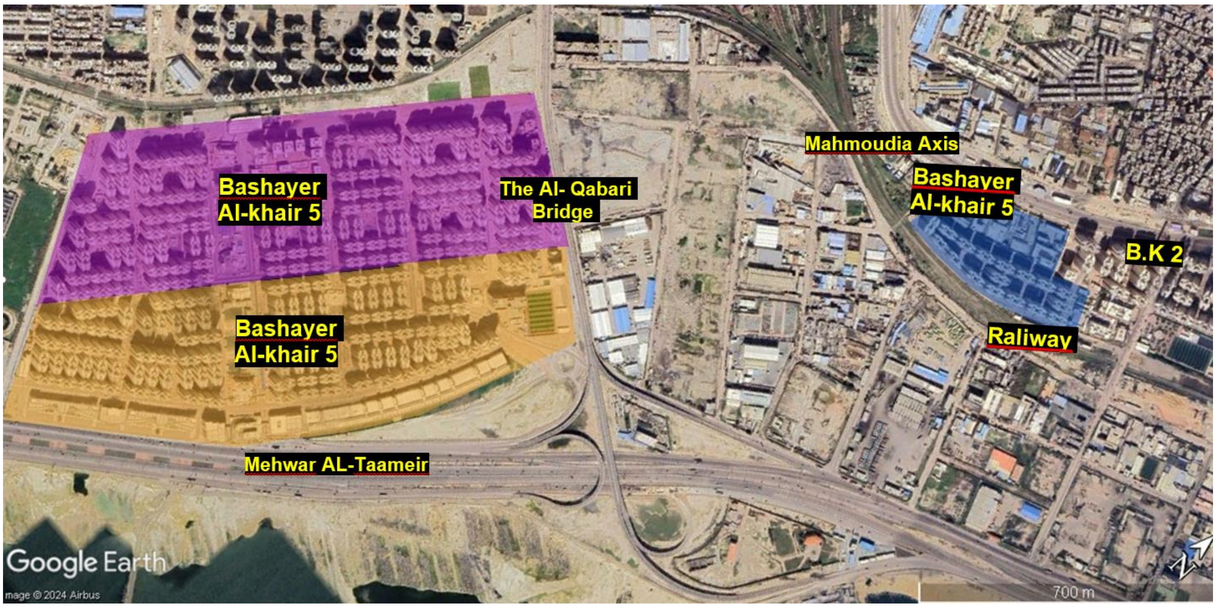


Figure 4. The image shows the three locations of the Bashayer El- Khair projects in Alexandria [34]

2.5. The Case Study (Bashayer Al-Khair Housing Projects)

As shown in Figure 5, Bashayer Al-Khair is the most significant national block area project in the area of slum development, aimed at reviving slums into developed and civilized areas [31]. The project encompasses not just housing areas, but also shopping malls, mosques, hospitals, churches, and craft centres with the aim of developing these areas [32]. Project phases:

Bashayer Al-Khair 1, 2, 3, 5 (West Alexandria)

Bashayer Al-Khair 4 (Rashid)

Figure 5. The Bashayer Al-Khair Housing Project, a massive residential project in Alexandria, Egypt [35]

720 square meters are divided into two structures, each encompassing an area of 360 square meters and containing four apartments, which includes three bedrooms, a toilet, kitchen and reception with the apartment having a total area of 90 square meters [33] (Figure 6).

The Bashayer Al-Khair social housing project represents a typical example of urban morphology in affordable housing schemes within Mediterranean contexts. The three phases (1, 3, and 5) illustrate common design features such as high density, repetitive block layouts, and uniform building orientations, which primarily respond to economic considerations and land-use efficiency. However, the analysis reveals that variations in density, height-to-width ratio (H/W), and inter-block spacing across the phases may influence outdoor thermal comfort (OTC), as also highlighted in previous studies addressing the role of urban form in shaping microclimatic conditions.

Table 1 highlights the differences in density indicators and urban form parameters for the three phases. These variations serve as key explanatory factors for discrepancies in thermal comfort levels. For instance, higher site coverage (construction percentage) and floor area ratio (FAR) generally correlate with increased urban density, which may restrict wind circulation and ventilation potential, thereby affecting microclimatic conditions such as perceived air temperature and outdoor comfort levels.

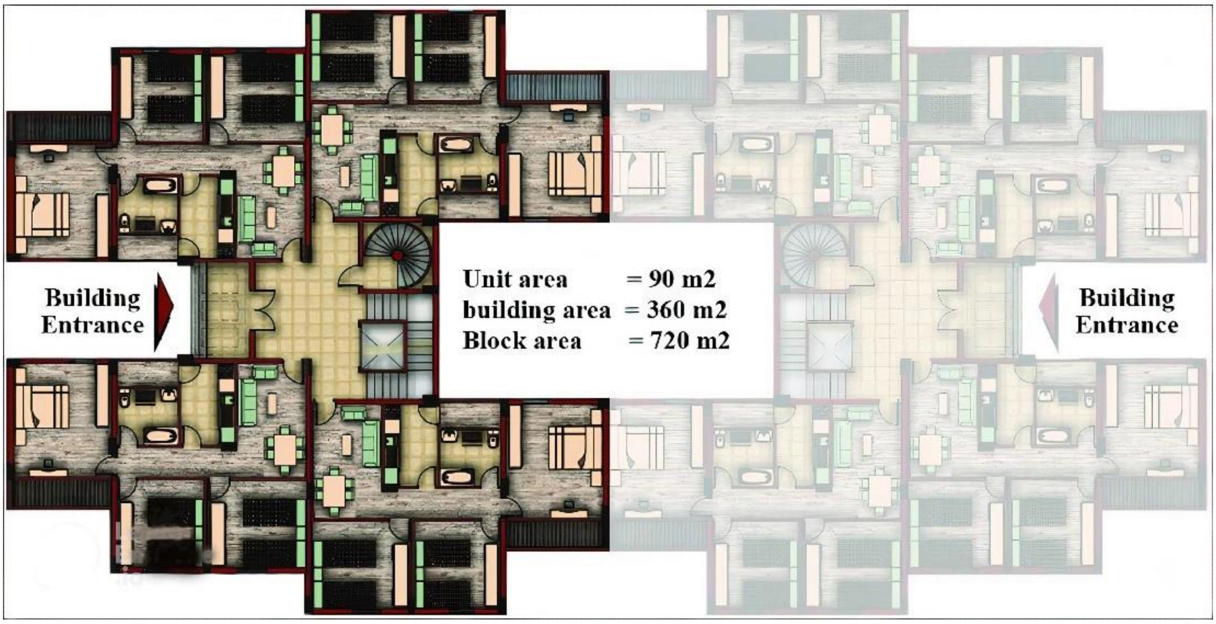


Figure 6. Bashayer Al-Khair Housing Project plan shows four apartments in a block with a total area of 90 m^2 [35]

- **Bashayer Al-Khair (1)**

The Bashayer Al-Khair (1) project is focused on redeveloping 'Ghait Al-Enab', an area in Alexandria, as its main objective. The primary objective of this project is to enhance the quality of life in informal settlements and to facilitate access to affordable housing for low-income households. Their cooperation with the society was instrumental in implementing the strategy, not just for the development of Ghait Al-Enab, the Bashayer Al-Khair district in Alexandria, Egypt, which is located at approximately 31°10'27.66" N latitude and29°53'48.86" E longitude. Nevertheless, replacing it with an effective social housing option for low-income families is necessary. Bashayer Al-Khair (1)'s total area is 51,743 square meters, but only 36,280 square meters of it are used for the residential complex. There are 17 blocks in the block that have ground floor levels and 11 stories, and all of them feature a similar format.

Bashayer El-Khair (1) is broken up into two main zones: one is the residential area, which is exclusively for housing and contains establishments like primary and preparatory schools. To the north, it is surrounded by a residential area and various educational institutions. The second one, the expansion project of Bashayer Al-Khair (2) to the north, can be seen from the Service Zone (Figure 7). Bashayer Al-Khair (1) and its surrounding developments benefit from the essential amenities provided by the service zone. Located near the El-Mahmoudia highway to the north, these two zones are strategically placed near each other and were heavily redeveloped in 2018. To the south, it is viewed as a goods railway, and to the east, it is viewed over a 17-meter-wide street that overlooks Bashayer Al-Khair (2) and the Armed Forces yard in Ghait Al-Enab [31] (Figure 4).

Figure 7. Bashayer Al-Khair (1) Housing Project with multi-story residential buildings and an organized layout [35]

- **Bashayer Al-Khair (3)**

Bashayer Al-Khair 3 is a massive public housing project that aims to improve the living conditions of low-income communities in Alexandria, Egypt, (31°9'40"N 29°53'9"E), an area that has been developed as “Maawa al-Sayadeen”. Bashayer Al-Khair (3) has a total area of around 63.5 acres (about 257,000 square meters). The process began in 2014, and the phases were finished in the following years. After 2019, this is the most recent phase that has been developed. As shown in Figure 8, there are two main zones in Bashayer El Khier (3). The Residential Zone is the initial one, comprising 200 buildings with a total of 10624 housing units for approximately 53120 people. There is a youth center, hospital, five mosques, a church, and a post office in the second zone, which has 33 classrooms and three schools (Figure 9). The width of main streets is designed to accommodate both pedestrian and vehicle traffic. The width of main streets is usually 12 to 15 meters. Secondary streets in residential zones are slightly narrower, with a typical width of 8 to 10 meters. The Mahmudiya Axis, which runs through the northern areas of Alexandria, is where Bashayer Al-Khair 3 is situated. The Tameer axis, which runs close to Karmouz, defines the western boundary. To the west of Bashayer Al-Khair 3 is where Bashayer Al-Khair 5 is situated (Figure 4) [33]. The south, New International Street, with a width of 16 meters, overlooks Alexandria West Sewage Treatment Plant [36].

Figure 8. The service zone (youth center, mosque, church, and three schools) [37]

Figure 9. Bashayer Al-Khair (3-5) Housing Project with multi-story residential buildings and an organized layout [37]

- **Bashayer Al-Khair (5)**

Bashayer El-Khair 5 is a large redevelopment project in Alexandria's Gharb district, replacing the former slum area of Al-Qabari with 15,200 housing units for about 76,000 residents, along with extensive services and commercial facilities. The project is strategically linked to major roads and landmarks such as Al-Qabari Bridge and the New International Street.

2.6. Population Density for Housing Project

As shown in Table 1, the construction percentages of Bashayer Al-Khair (3) and (5) are significantly higher (58.2% and 54.7%) than those of Bashayer Al-Khair (1) (23.7%). Bashayer Al-Khair (1) has a floor area ratio of 2.61, while Sites 3 and 5 have much higher ratios (8.15 and 7.66, respectively).

3. Results

The case study examination determines the thermal environment of the roads in affordable housing in Alexandria. Simulations took place in Alexandria during the hot season (August), starting at 1:00 PM LST. The simulations focused solely on the building fabric and surrounding streets (without modelling urban trees), and urban canyons are only affected by different patterns.

- **For case (1) rectangular courtyard**

The simulation software tool of the ENVI-met program is currently examining a number of residential buildings in Bashayer Al-khair (1) in this section **(**Figure 10). There are 17 buildings in the cluster, along with a general street and sidewalk, as shown in Table 1. The floor area ratio of the site equal to 2.61 is generally considered moderate to low depending on the context of urban planning.

The simulation sequence consists of the following: ENVI-met was utilized to simulate the base case at 1:00 p.m. on August 15, and the ENVI-met model was run for one hour. Accordingly, the results presented in this study reflect the conditions observed at 2:00 p.m., an air temperature of 31℃, and a wind flow of 4.7 m/s. Measurements were taken at 1 p.m. on August 15th, as shown in Table 2. The total model area 480 m^2 × 230 m^2 regions produce with X-Grids: 240 and the Y-Grids 115 grid with grid dimensions Margin grids should be created by the software for the dimensions of dx = 2.00 m and dy = 2.00 m, respectively, of the structure in the main area. The max building height is 35 meters, the boundary layer's umbrella is included in the canopy layer, and the maximum building height was modelled using z-Grid: 21 and a grid size of dz = 6.00 m to double its height to 105 m. The ENVI-MET software's maximum acceptable grid number for simulation is (150 ×135 ×21 grid), and these numerical statistics are defined below it. According to the simulation results for the rectangular courtyard, the average wind speed was 3.4 m/s, while the air temperature ranged from 25.38℃ to 28.39℃, and the relative humidity varied between 74.45% and 86.94%. These climatic parameters provide a comprehensive overview of outdoor thermal comfort conditions in the studied area (Figure 11, Figure 12, Figure 13).

Figure 10. The cluster modeling of Bashayer Al-Khair 1 residential buildings (ENVI-Met Screenshot) is being shown

Table 2. Plot area data in ENVI-met program

Plot area	total area, building heights	480 m × 230 m
		35 m
	Number of blocks	17 blocks
	maximum acceptable grid number	(240 × 115 × 21)
	North Arrow	12 °
	Framework in grid	dX = 2.00 m, dY= 2.00 m and dZ = 6.00 m
Floor area ratio		2.61

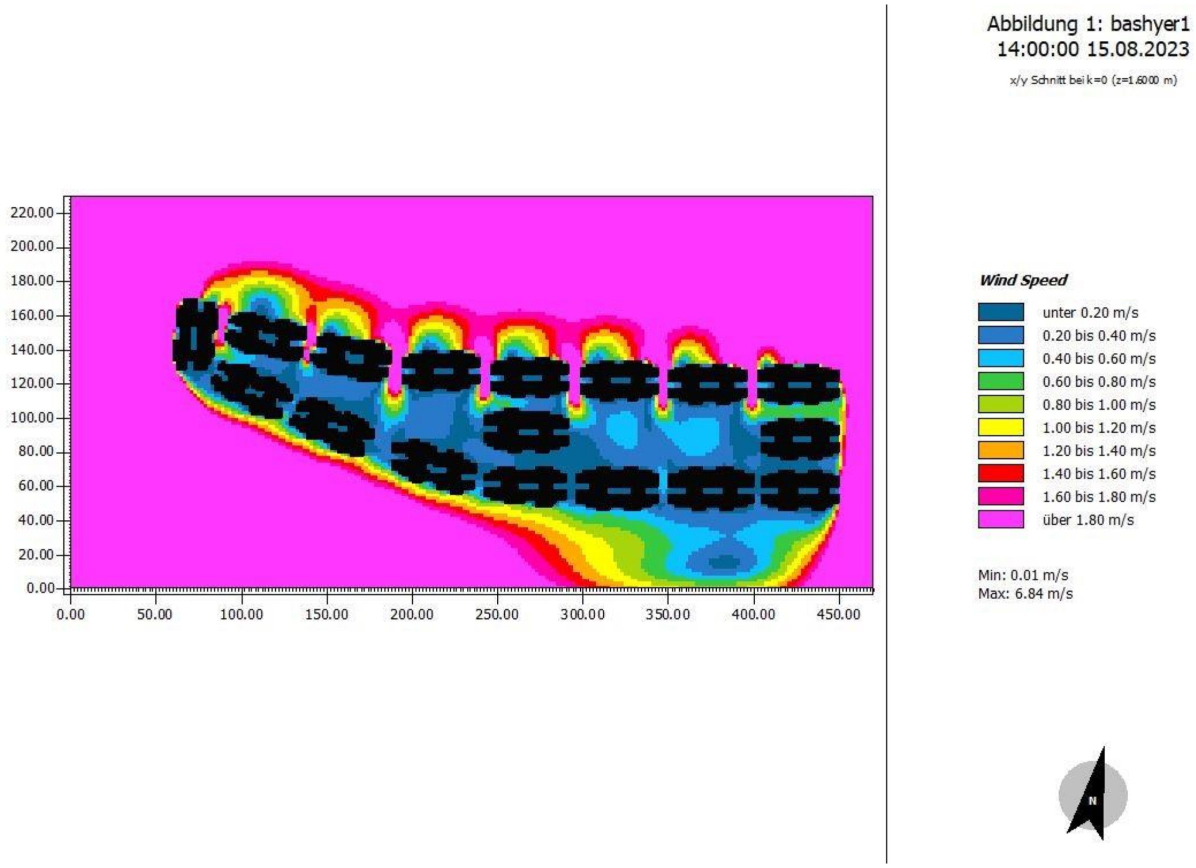


Figure 11. ENVI-met result of wind speed at 2 p.m. on August 15 for case bashayer Al-Khair (1) (ENVI-met Screenshot)

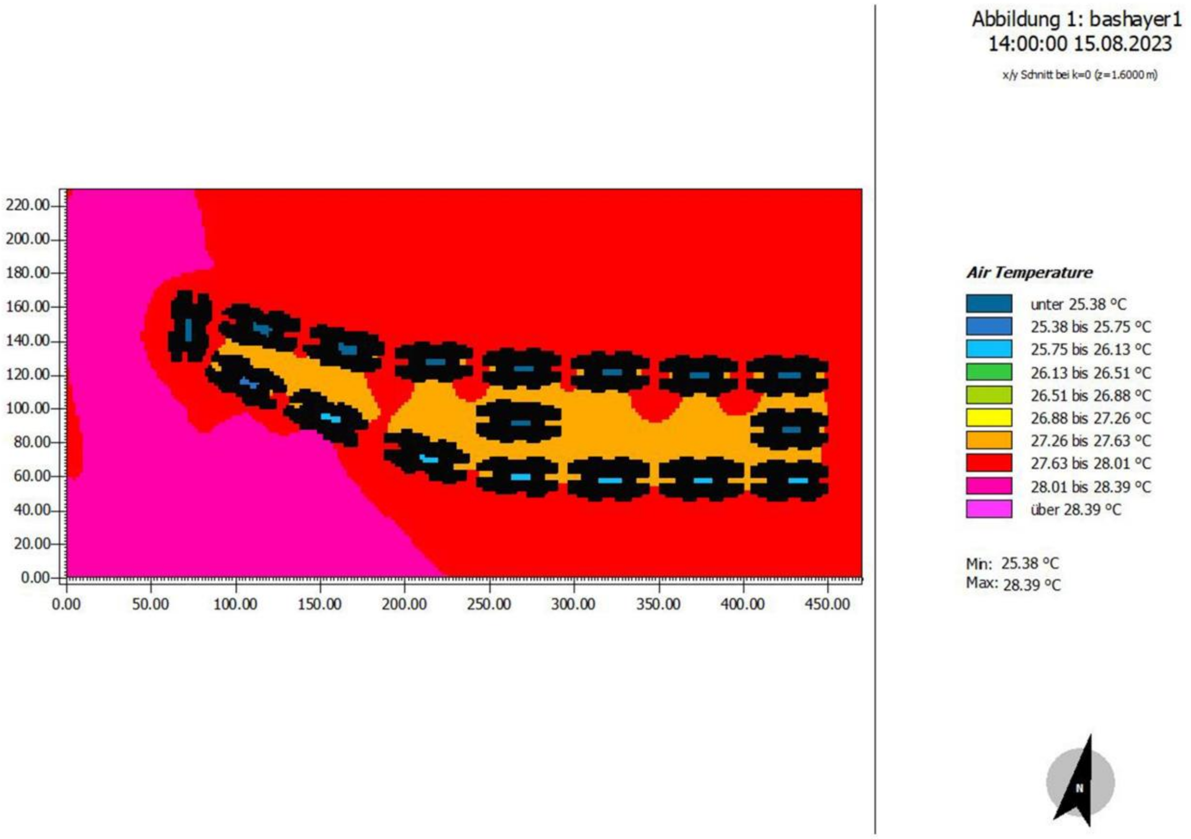


Figure 12. ENVI-met result of air temperature at 2 p.m. on August 15 for case bashayer Al-Khair (1) (ENVI-met Screenshot)

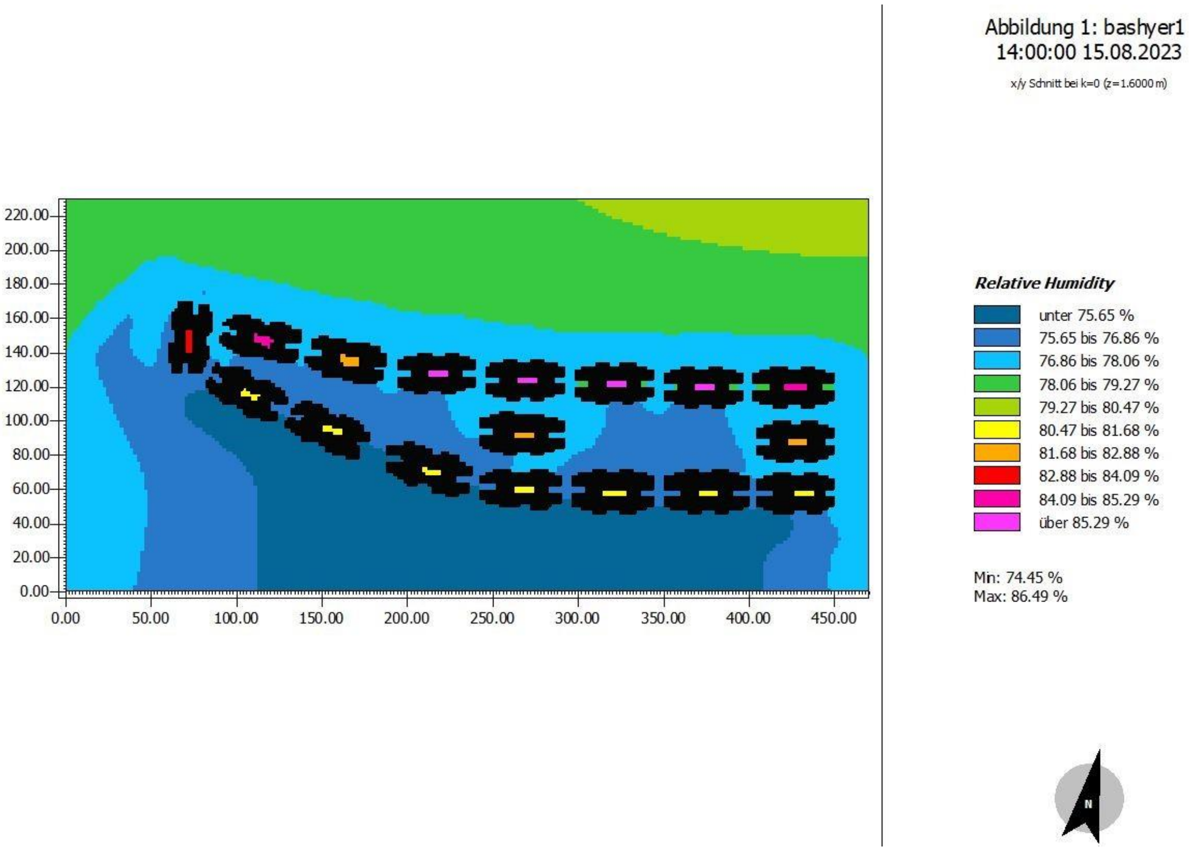


Figure 13. ENVI-met result of relative humidity at 2 p.m. on August 15 for case bashayer Al-Khair (1) (ENVI-met Screenshot)

- **For case (2) linear**

In this part, the simulation software tool of the ENVI-met program is examining a number of residential buildings in Bashayer Al-khair (3) (Figure 14). There are 14 buildings in the cluster, as well as a street and sidewalk, as shown in Table 1. Based on the floor area ratio of 8.15, the site is generally regarded as having a high-density use of the land parcel.

The simulation process is described as follows: ENVI-met was utilized to simulate the base case at 1:00 p.m. on August 15, the ENVI-met model was run for one hour. Accordingly, the results presented in this study reflect the conditions observed at 2:00 p.m., an air temperature of 32 ℃, and a wind flow of 4.7 m/s. The satellite image drawings were used to create the area file model for the case study, as shown in Table 3. The total model area 320 m^2 × 200 m^2 and regions create with X-Grids: 160 and the Y-Grids 100 grid with grid size. The software's recommendation for creating margin grids is to construct the main zone with dx = 2.00 m and dy = 2.00 m, the building can be as high as 41 meters, including the canopy layer below the boundary layer, and the z-Grid: 21 and grid size of dz = 6.00 m were utilized to model the maximum building height being doubled to 123 meters. ENVI-Met software determined that these numerical statistics are within permissible grid limits, which is (160 × 100 × 21 grid). According to the simulation results for the rectangular courtyard, the average wind speed was 3.5 m/s, while the air temperature ranged from 26.92 ℃ to 30.26 ℃, and the relative humidity varied between 75.07% and 88.94%. These climatic parameters provide a comprehensive overview of outdoor thermal comfort conditions in the studied area (Figure 15, Figure 16, Figure 17).

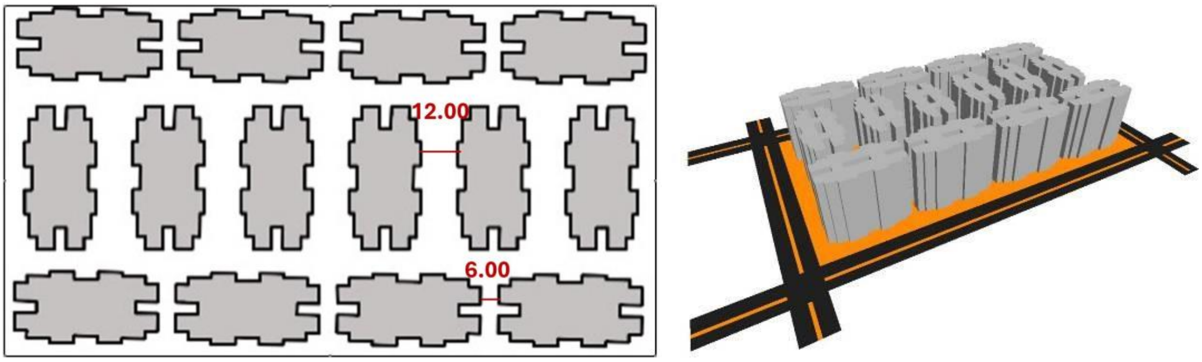


Figure 14. The cluster modeling of Bashayer Al-Khair 3 residential buildings (ENVI-Met Screenshot) is being shown

Table 3. Plot area data in ENVI-met program

Plot area	total area, building heights	320 m × 200 m
		41 m
	Number of blocks	14 blocks
	maximum acceptable grid number	(160 × 100 × 21)
	North Arrow	35º
	Framework in grid	dX = 2.00 m, dY= 2.00 m and dZ = 6.00 m
Floor area ratio		8.15

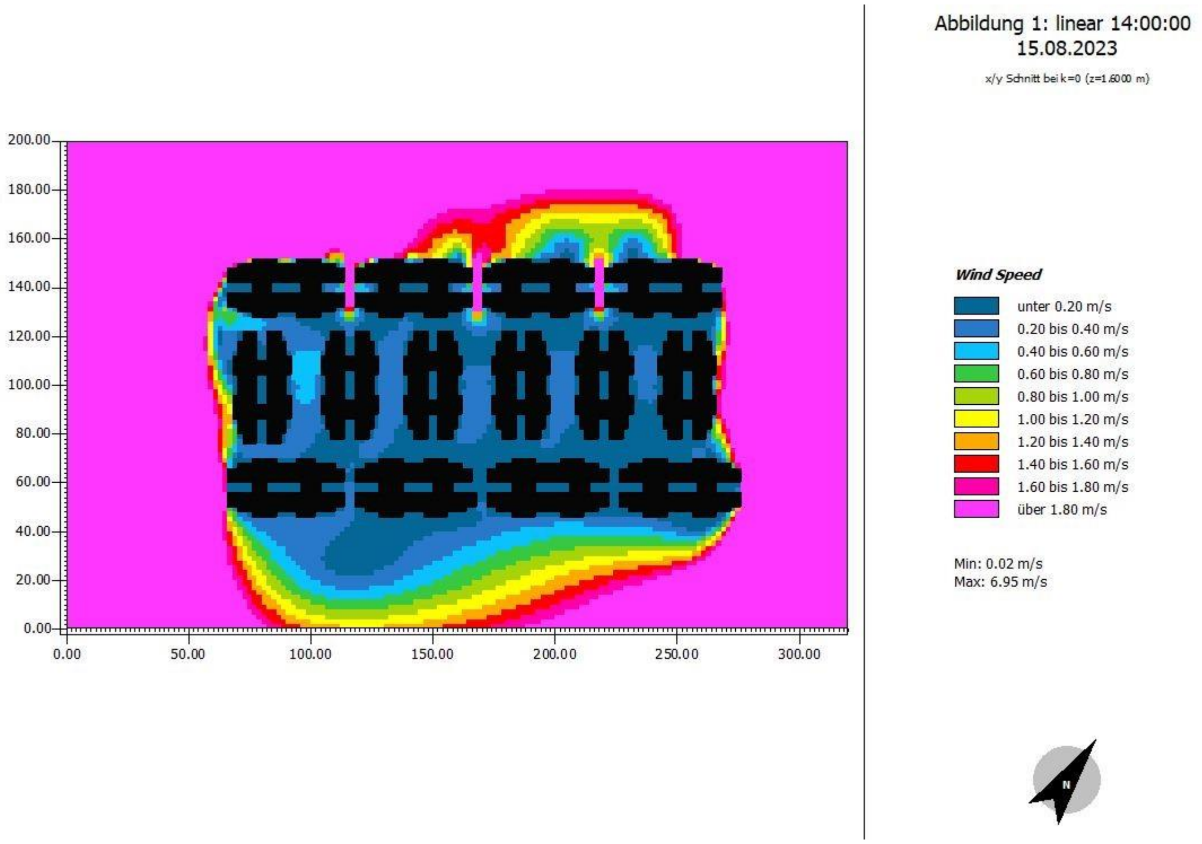


Figure 15. ENVI-met result of wind speed at 2 p.m. on August 15 for case Bashayer Al-Khair (3) (ENVI-met Screenshot)

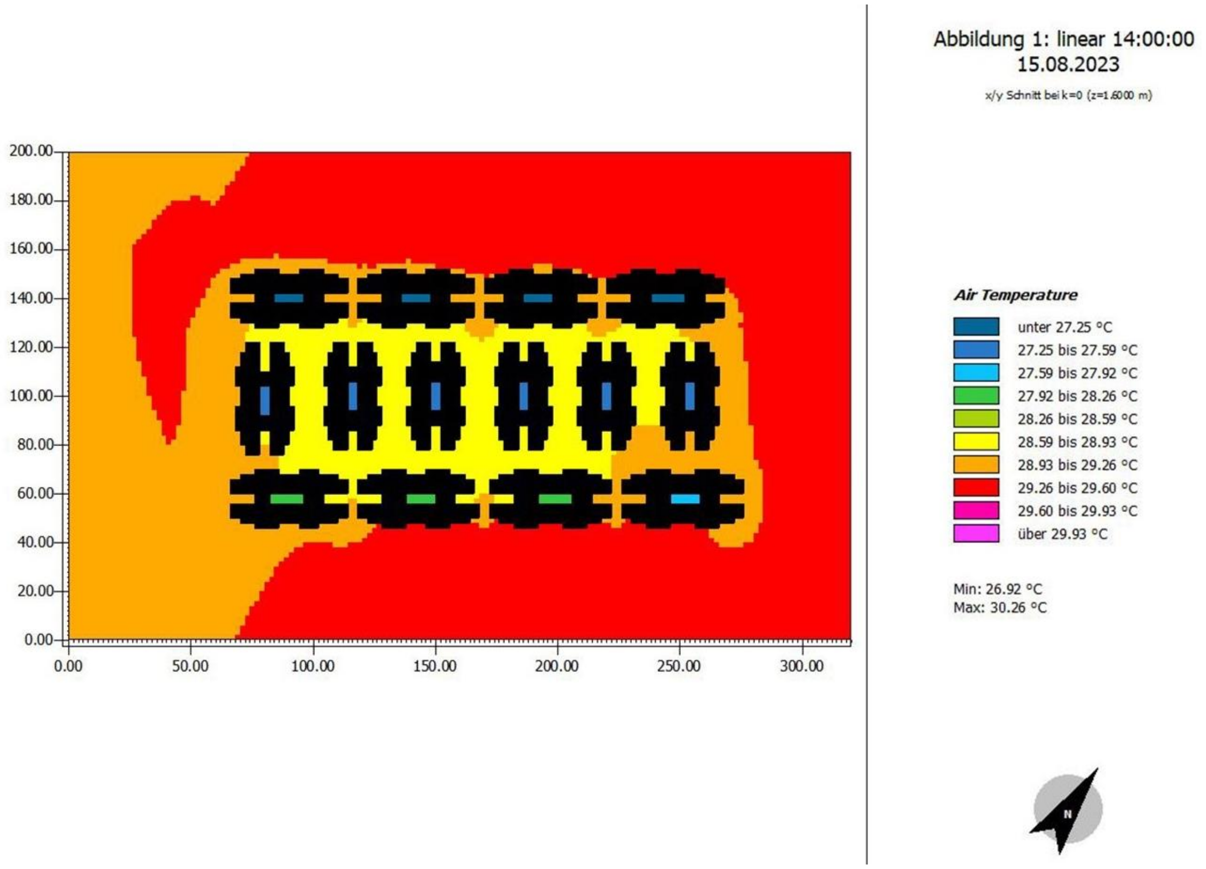


Figure 16. ENVI-met result of air temperature at 2p.m. on August 15 for case Bashayer Al-Khair (3) (ENVI-met Screenshot)

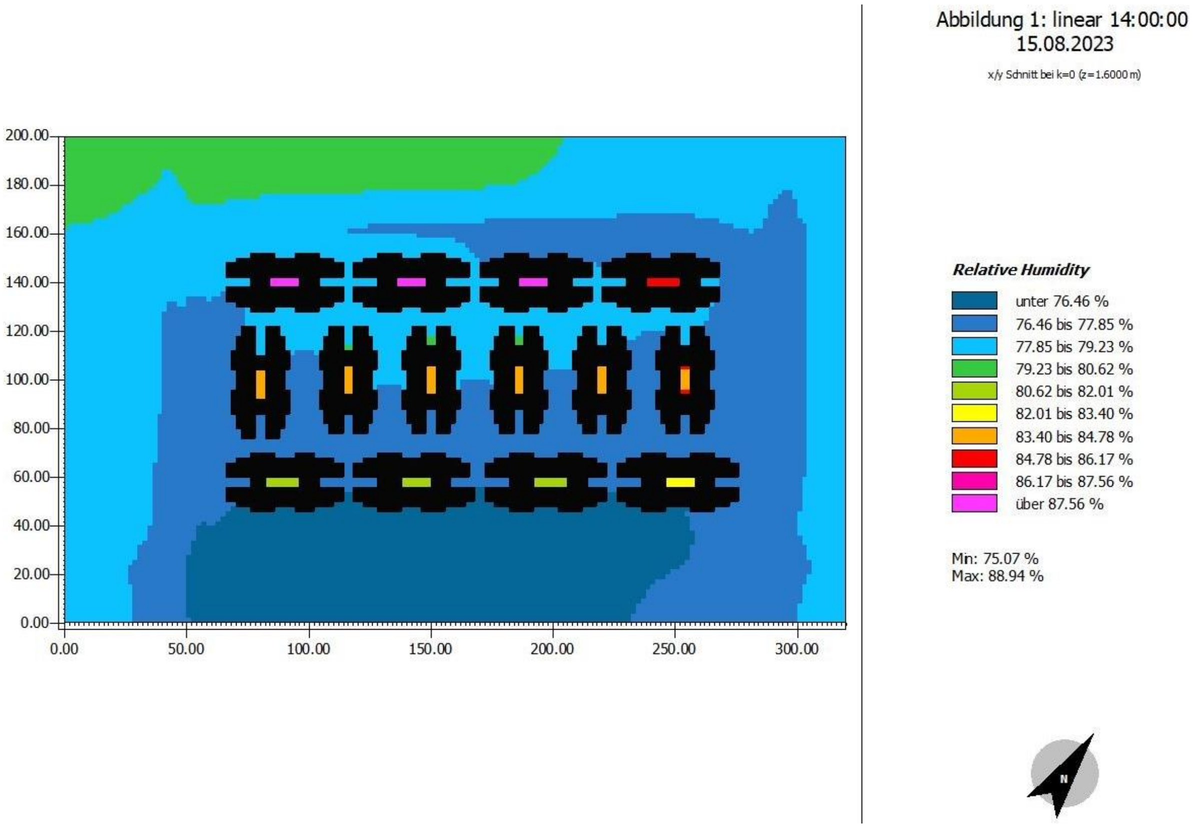


Figure 17. ENVI-met result of relative humidity at 2 p.m. on August 15 for case Bashayer Al-Khair (3) (ENVI-met Screenshot)

- **For case (3) Square courtyard**

The simulation software tool of the ENVI-met program is examining some residential buildings in Bashayer Al-khair (5) in this section (Figure 18). There are 16 buildings in the cluster, as well as a general street and sidewalk, as shown in Table 1. The floor area ratio of 7.66 would be considered high and ideal for high-density construction.

The simulation sequence consists of the following: ENVI-met was utilized to simulate the base case at 1:00 p.m. on August 15, and the ENVI-met model was run for one hour. Accordingly, the results presented in this study reflect the conditions observed at 2:00 p.m., an air temperature of 32 ℃, and a wind flow of 4.7 m/s. The satellite image drawings were used to create the area file model for the case study, as shown in Table 4. The total model grid 280 m × 260 m regions are generated with X-Grids: 140 and the Y-Grids 130 grid with grid dimensions and framework in the main grid dx = 2.00 m and dy = 2.00 m. The software recommends the creation of margin grids, the maximum building height is 41 meters, and the model is based on a building height of 123 m, with a grid size of dz = 6.00 m, and a z-Grid of 21. The ENVI-MET software's maximum acceptable grid number for simulation is (150 × 135 × 21 grid). According to the simulation results for the rectangular courtyard, the average wind speed was 3.7 m/s, while the air temperature ranged from 24.01 ℃ to 27.46 ℃, and the relative humidity varied between 74.57 and 87.38%. These climatic parameters provide a comprehensive overview of outdoor thermal comfort conditions in the studied area (Figure 19, Figure 20, Figure 21).

The simulation results demonstrate a clear relationship between building typology, density, and microclimatic parameters such as wind speed, air temperature, and relative humidity.

For the rectangular courtyard, characterized by a lower floor area ratio (FAR = 2.61), the average wind speed was 3.4 m/s, with air temperatures ranging from 25.38 ℃ to 28.39 ℃ and relative humidity between 74.45% and 86.94%. The lower density and elongated layout allowed for moderate wind penetration and slightly lower temperatures.

In contrast, the linear layout, which exhibited the highest density (FAR = 8.15), recorded an average wind speed of 3.5 m/s and higher air temperatures (26.92 ℃ – 30.26 ℃) with relative humidity ranging from 75.07% to 88.94%. The compact, linear arrangement reduced airflow paths, leading to higher temperatures and humidity accumulation compared to the rectangular courtyard.

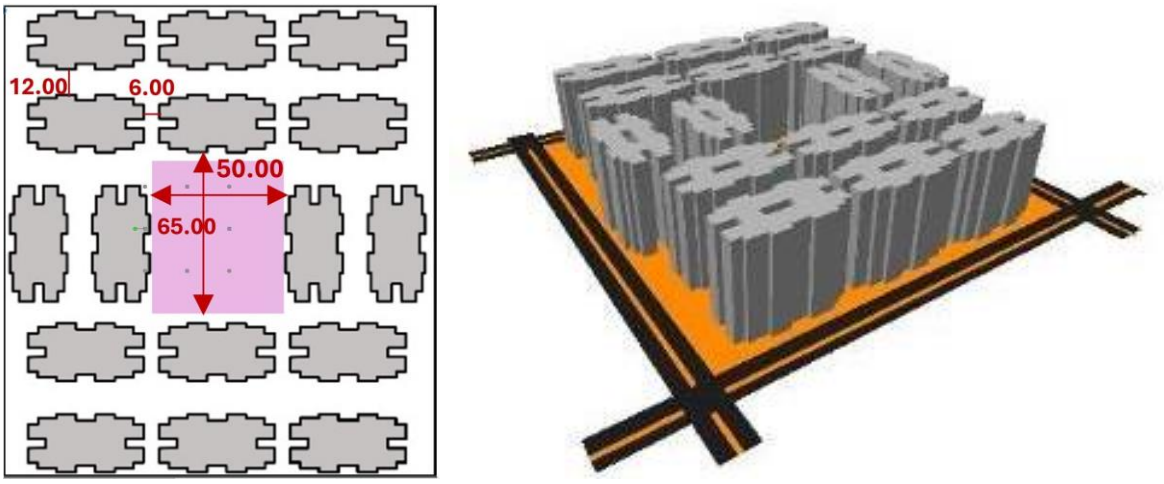


Figure 18. The cluster modeling of Bashayer Al-Khair 5 residential buildings (ENVI-Met Screenshot) is being shown

Table 4. Plot area data in ENVI-met program

Plot area	total area, building heights	280 m × 260 m
		41 m
	Number of blocks	16 blocks
	maximum acceptable grid number	(150 × 135 × 21)
	North Arrow	35º
	Framework in grid	dX = 2.00 m, dY= 2.00 m and dZ = 6.00 m
Floor area ratio		7.66

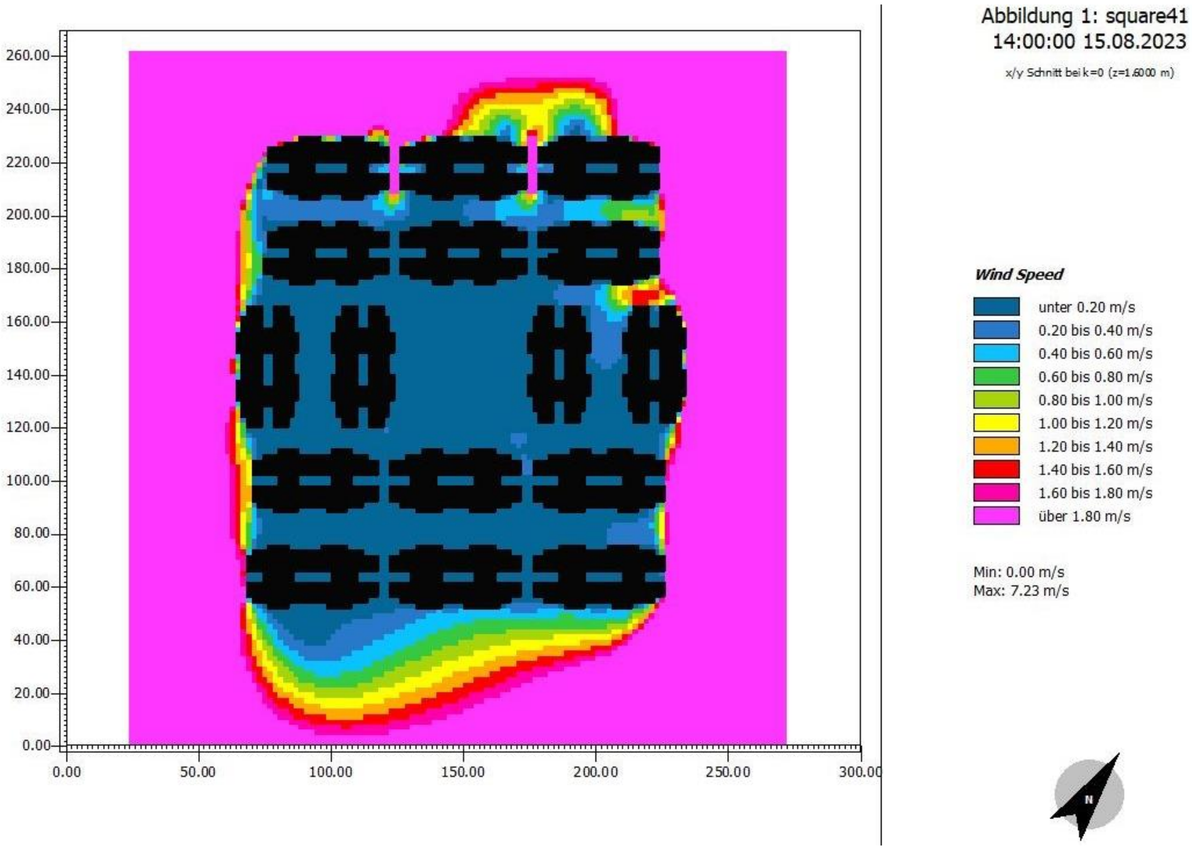


Figure 19. ENVI-met result of wind speed at 2 p.m. on August 15 for case Bashayer Al-Khair (5) (ENVI-met Screenshot)

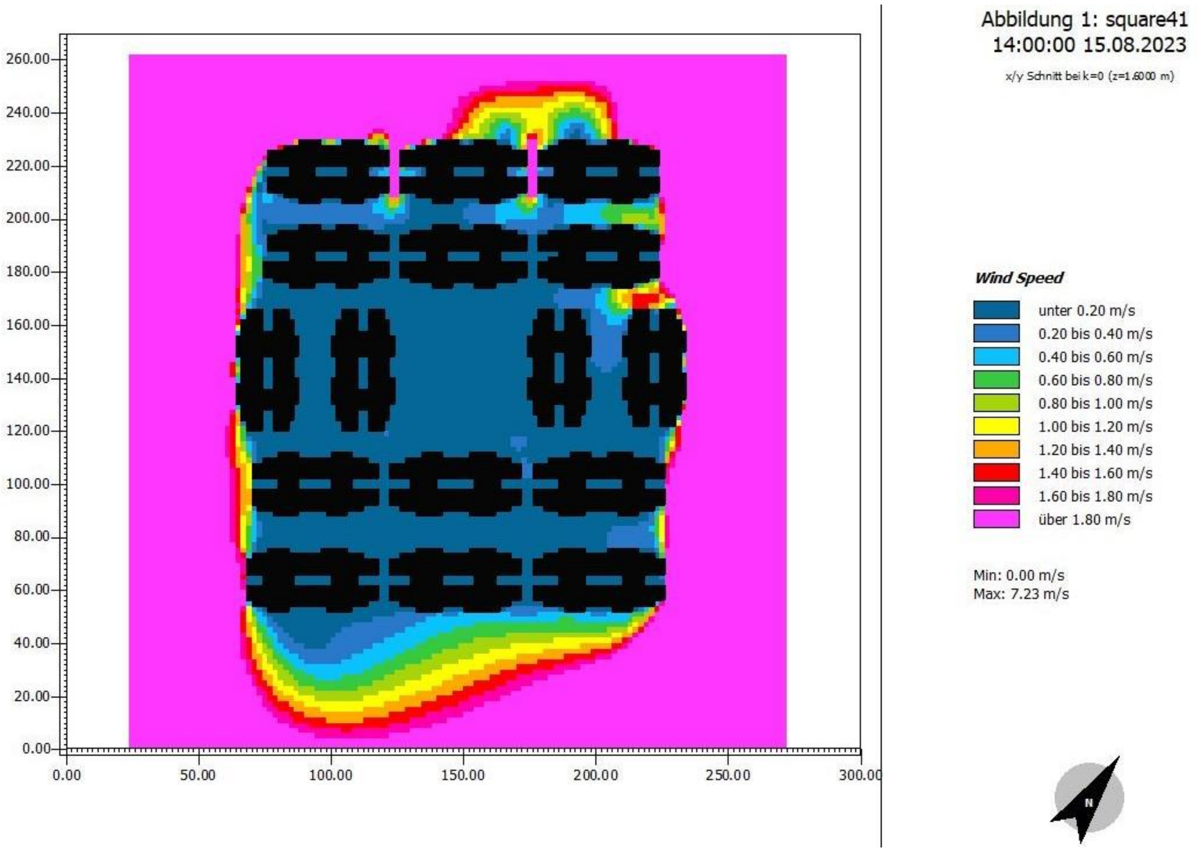


Figure 20. ENVI-met result of air temperature at 2 p.m. on August 15 for case Bashayer Al-Khair (5) (ENVI-met Screenshot)

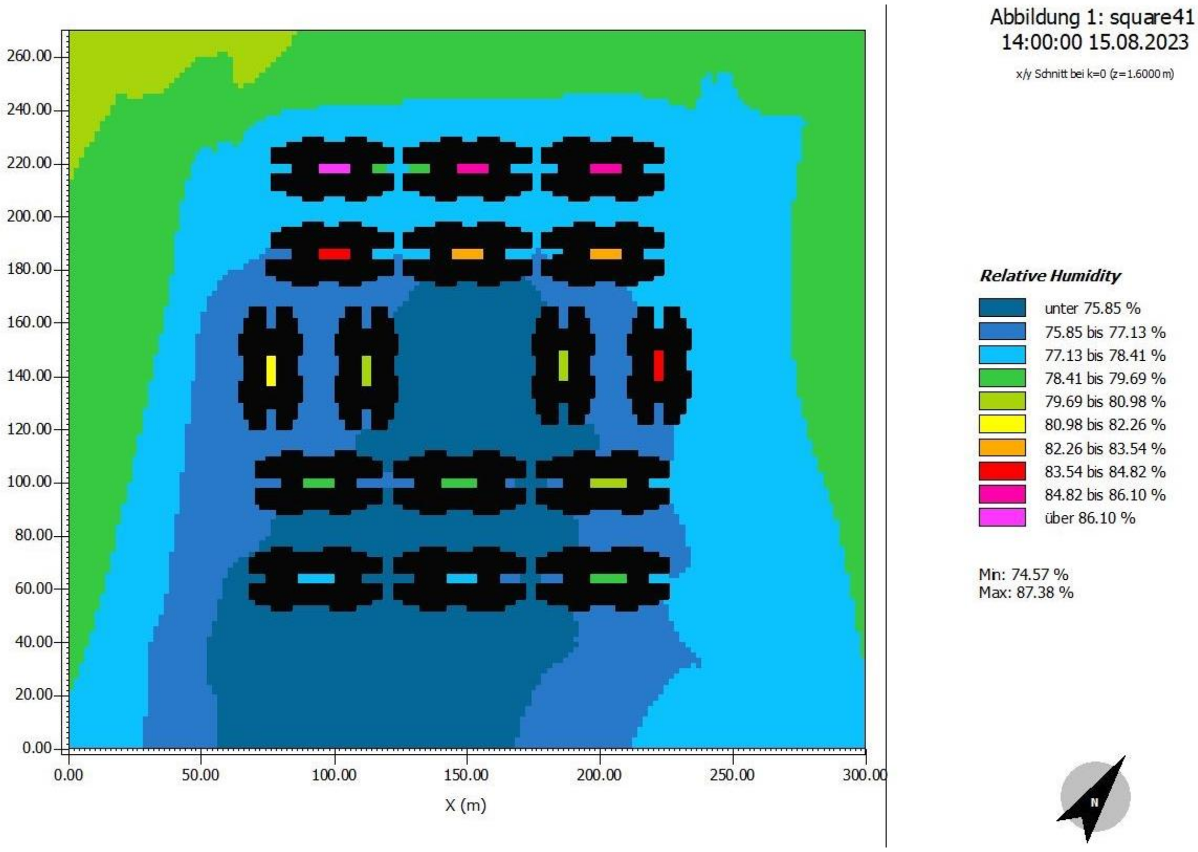


Figure 21. ENVI-met result of relative humidity at 2 p.m. on August 15 for case Bashayer Al-Khair (5) (ENVI-met Screenshot)

The square courtyard, with a FAR of 7.66, showed an average wind speed of 3.7 m/s, air temperatures between 24.01 ℃ and 27.46 ℃, and relative humidity from 74.57% to 87.38%. The square courtyard's central open space improved ventilation, which contributed to lower peak temperatures despite its relatively high density, as shown in Table 5.

Overall, the results indicate that lower-density, well-ventilated layouts, such as rectangular and square courtyards, are more effective in enhancing outdoor thermal comfort by reducing temperature peaks and facilitating airflow. Conversely, high-density linear configurations tend to restrict ventilation, leading to higher temperatures and humidity, which can negatively affect outdoor thermal comfort. These findings highlight the importance of considering both building typology and density in the design of high-rise residential complexes to optimize thermal comfort.

The Bashayer El-Kheir 5 model is the best case among the simulated cases because it achieves the best results.

To improve this approach, it is suggested to simulate a variety of scenarios with different height-to-width ratios of H to W (1.5, 2.5, 3.5, 4.5). In order to create design guidelines for similar urban developments, the study will evaluate key parameters such as wind speed, air temperature, and relative humidity in each scenario.

The simulation results indicate a clear impact of the height-to-width (H/W) ratio of urban canyons on wind speed, air temperature, and relative humidity:

For H/W = 1.5, the average wind speed was 2.25 m/s, with air temperatures ranging from 27.40 ℃ to 30.60 ℃ and relative humidity between 74.27% and 79.73% (average 77%). The low H/W ratio, representing shallower canyons, limited ventilation, and led to higher peak temperatures (Figure 22, Figure 23, Figure 24).

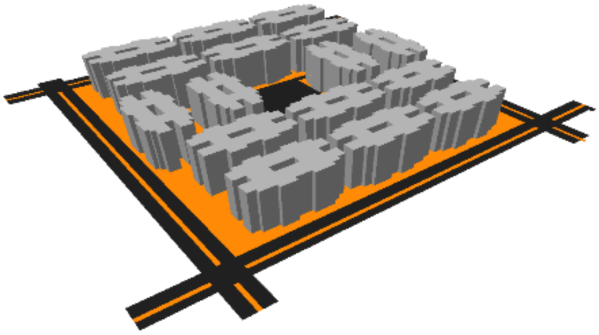
Increasing the ratio to H/W = 2.5 improved ventilation, yielding an average wind speed of 3.12 m/s, air temperatures from 26.28 ℃ to 29.23 ℃, and relative humidity between 74.55% and 81.92% (average 78%) (Figure 25, Figure 26, Figure 27).

For H/W = 3.5, wind speed increased to 3.7 m/s, with temperatures ranging from 24.01 ℃ to 27.46 ℃ and relative humidity from 74.57% to 87.38% (average 80.9%), showing that deeper canyons enhance airflow and slightly reduce peak temperatures (Figure 28, Figure 29, Figure 30).

Finally, at H/W = 4.5, the highest wind speed was observed at 3.83 m/s, while air temperatures ranged from 23.9 ℃ to 26.7 ℃, and relative humidity varied between 74.61% and 89.47% (average 82%). The tallest canyons further improved ventilation, leading to lower maximum temperatures but slightly higher humidity due to limited solar exposure (Figure 31, Figure 32, Figure 33).

Table 5. Comparative the Wind Flow, air temperature and relative humidity between case A rectangular courtyard, case B linear and case C square courtyard on August 15. Source: The researcher based on the data outputted from ENVI-met

Scenarios	Wind speed	Air Temperature			Relative Humidity			FLOOR AREA RATIO
	Average	Max	Min	Average	Max	Min	Average	
Rectangular courtyard	3.4	28.39	25.38	26.8	86.94	74.45	80.7%	2.61
Linear	3.5	30.26	26.92	28.6	88.94	75.07	82%	8.15
Square courtyard	3.7	27.46	24.01	25.7	87.38	74.57	80.9%	7.66

The Ratio of H/W
cluster modeling
H/W =1.5

ENVI-met result

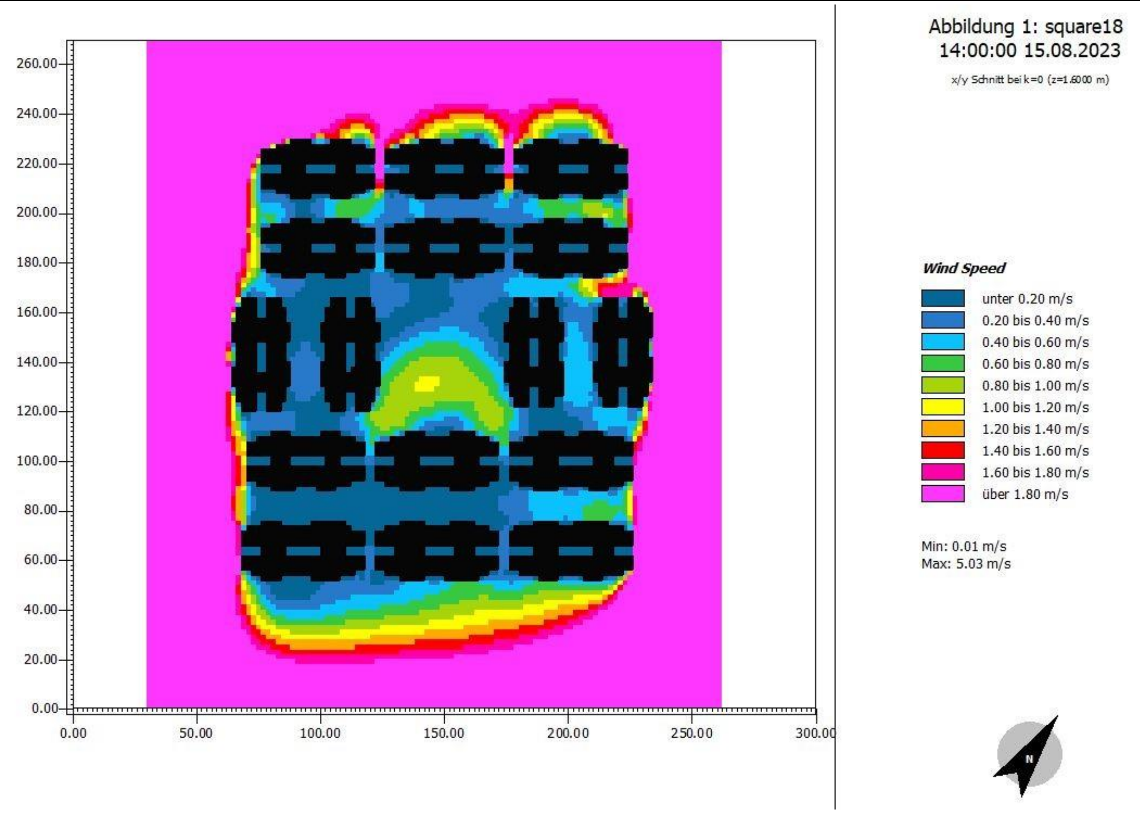


Figure 22. ENVI-met result of wind flow at 2 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 1.5

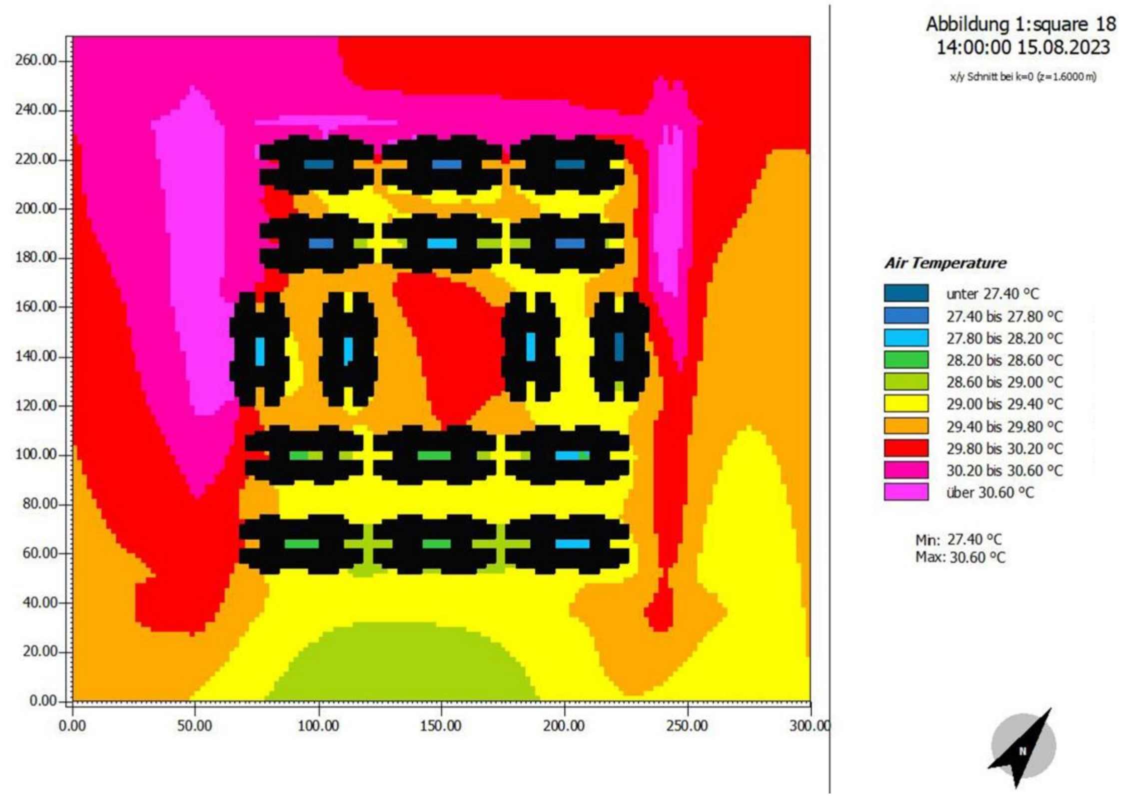


Figure 23. ENVI-met result of air temperature at 2 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 1.5

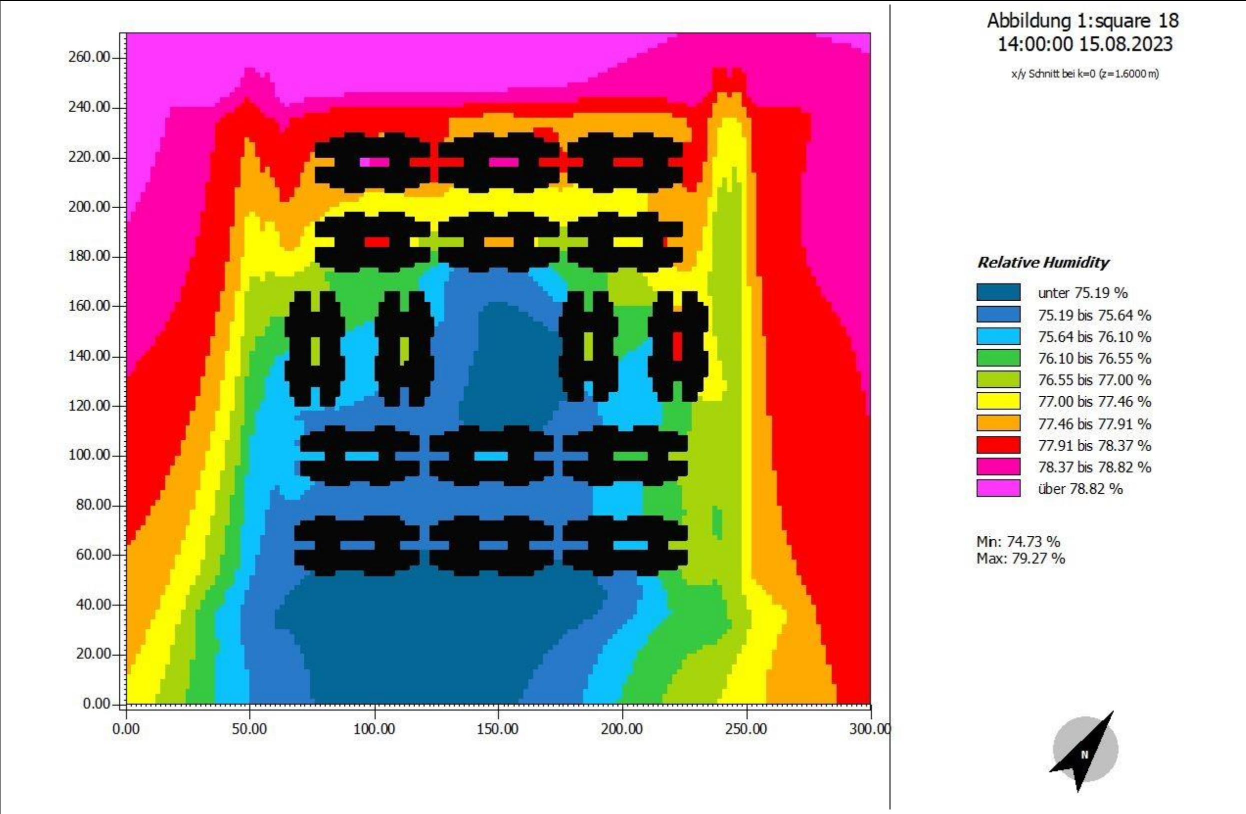
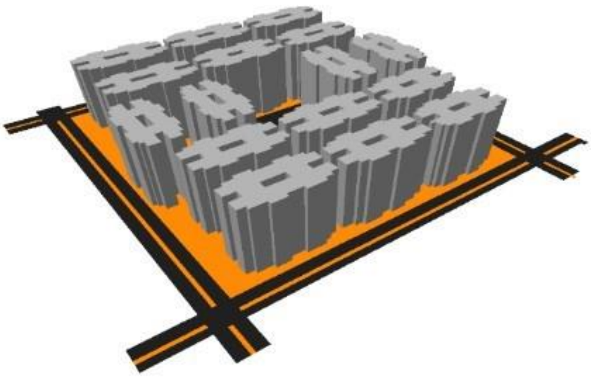


Figure 24. ENVI-met result of relative humidity at 2 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 1.5

H/W =2.5



ENVI-met result

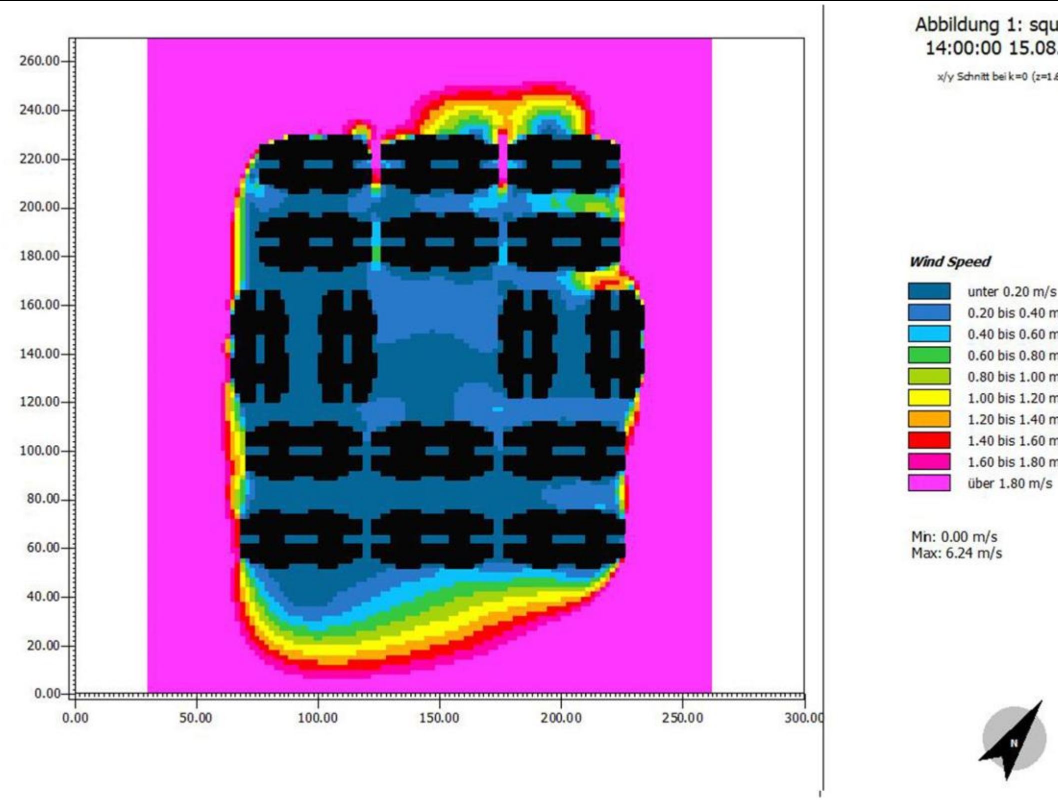


Figure 25. ENVI-met result of wind flow at 2 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 2.5

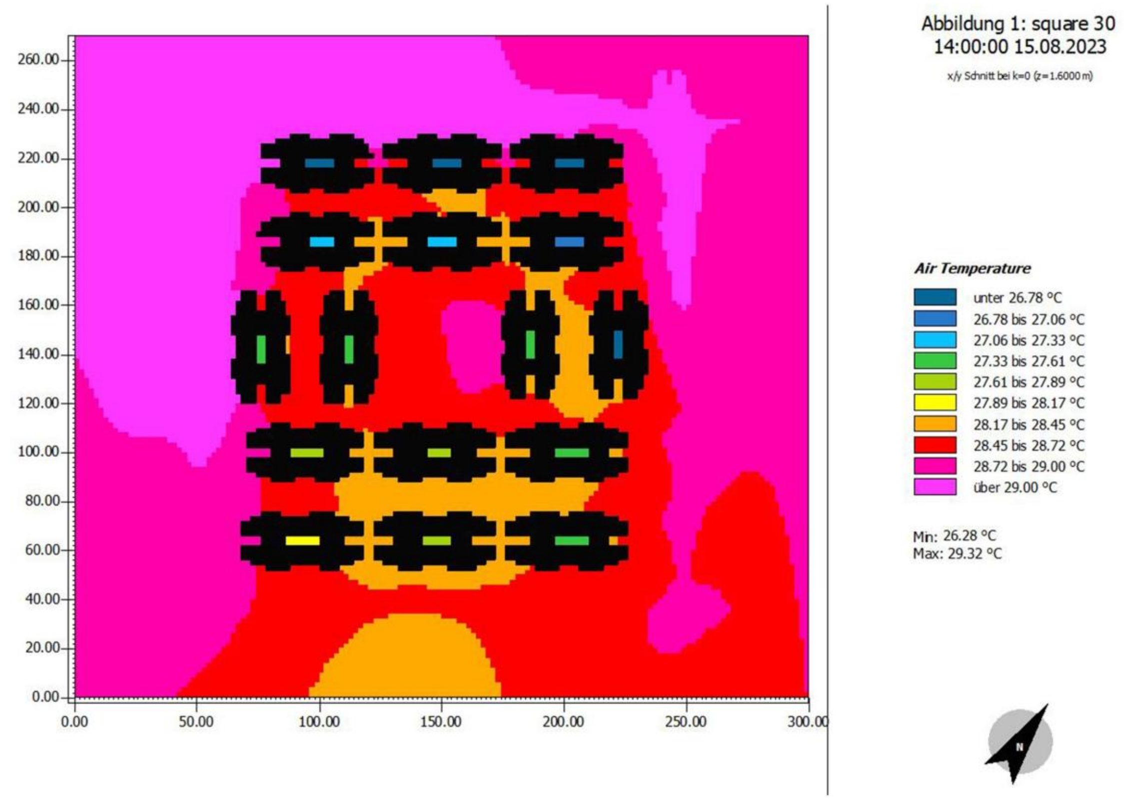


Figure 26. ENVI-met result of air temperature at 2 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 2.5

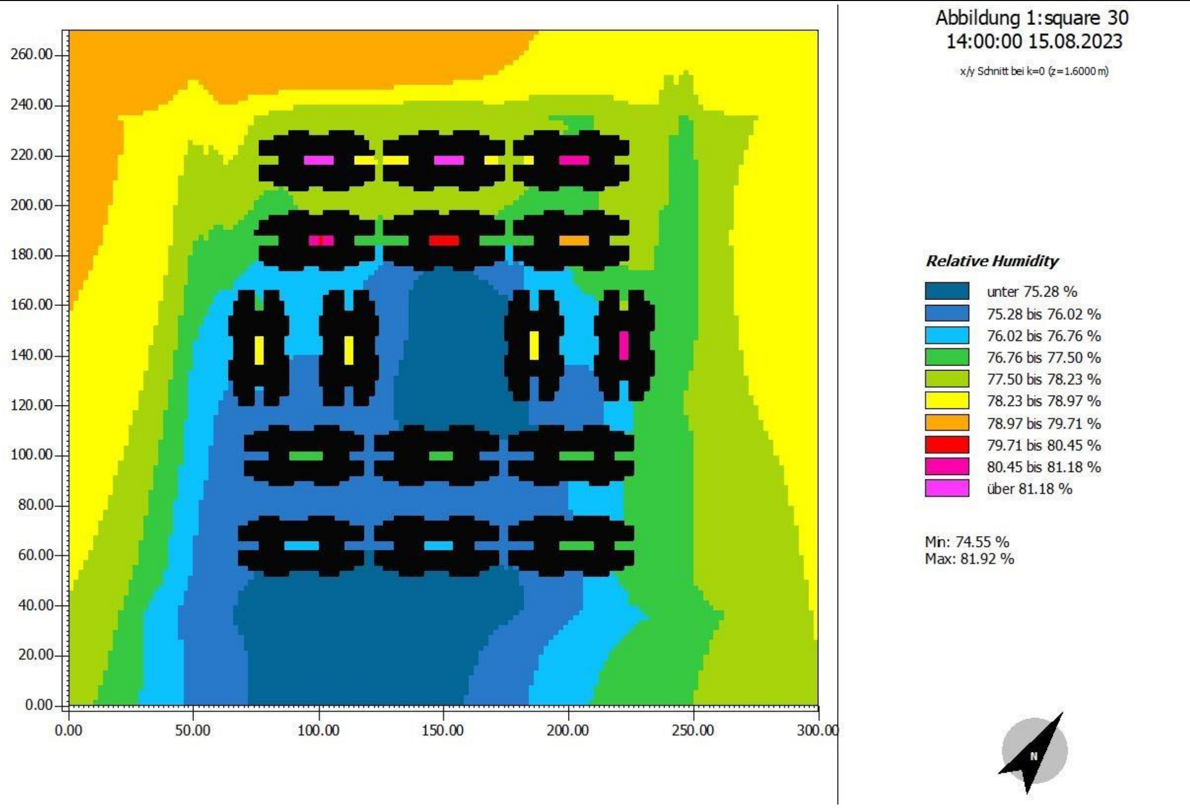
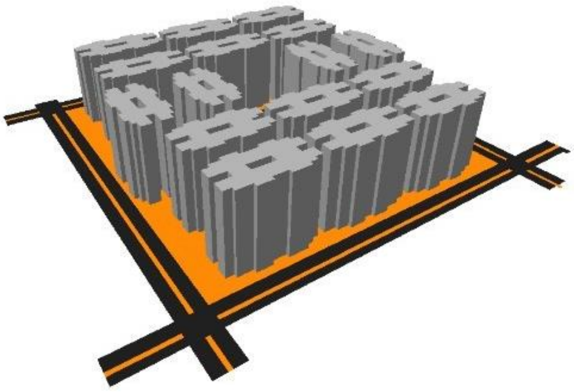


Figure 27. ENVI-met result of relative humidity at 2 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 2.5

H/W =3.5



ENVI-met result

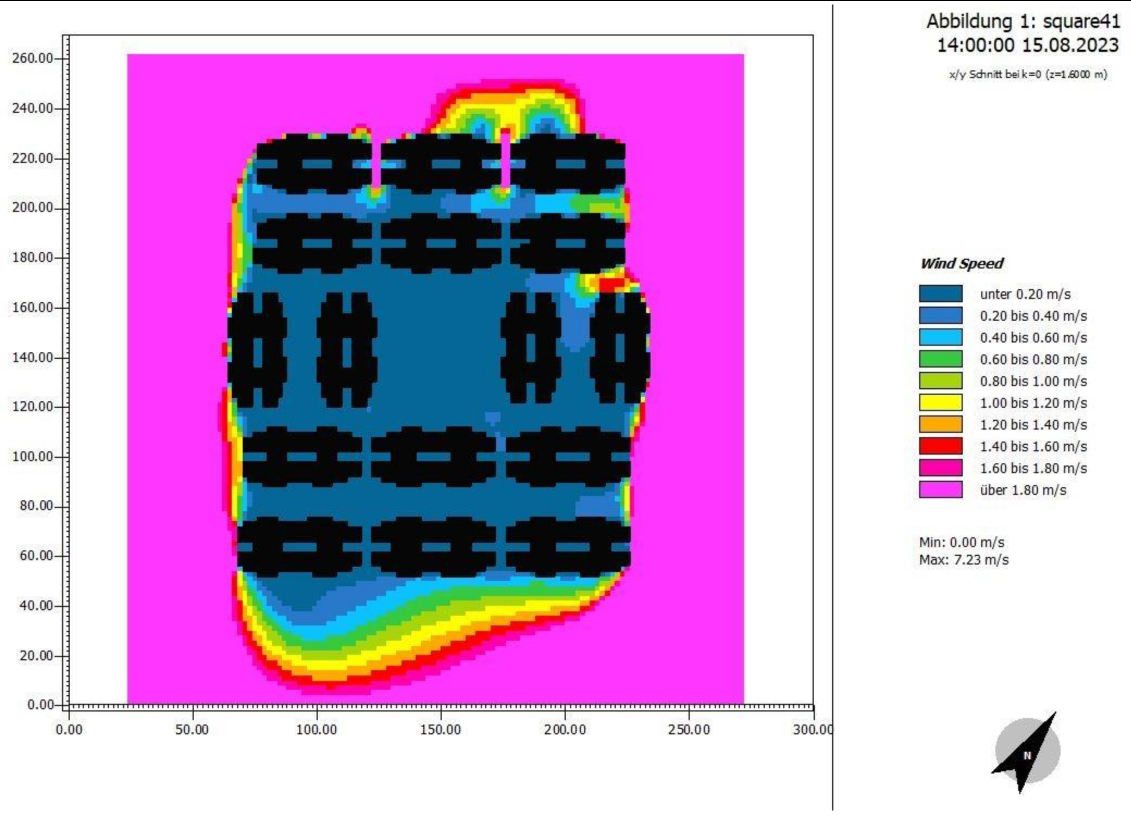


Figure 28. ENVI-met result of wind flow at 1 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 3.5

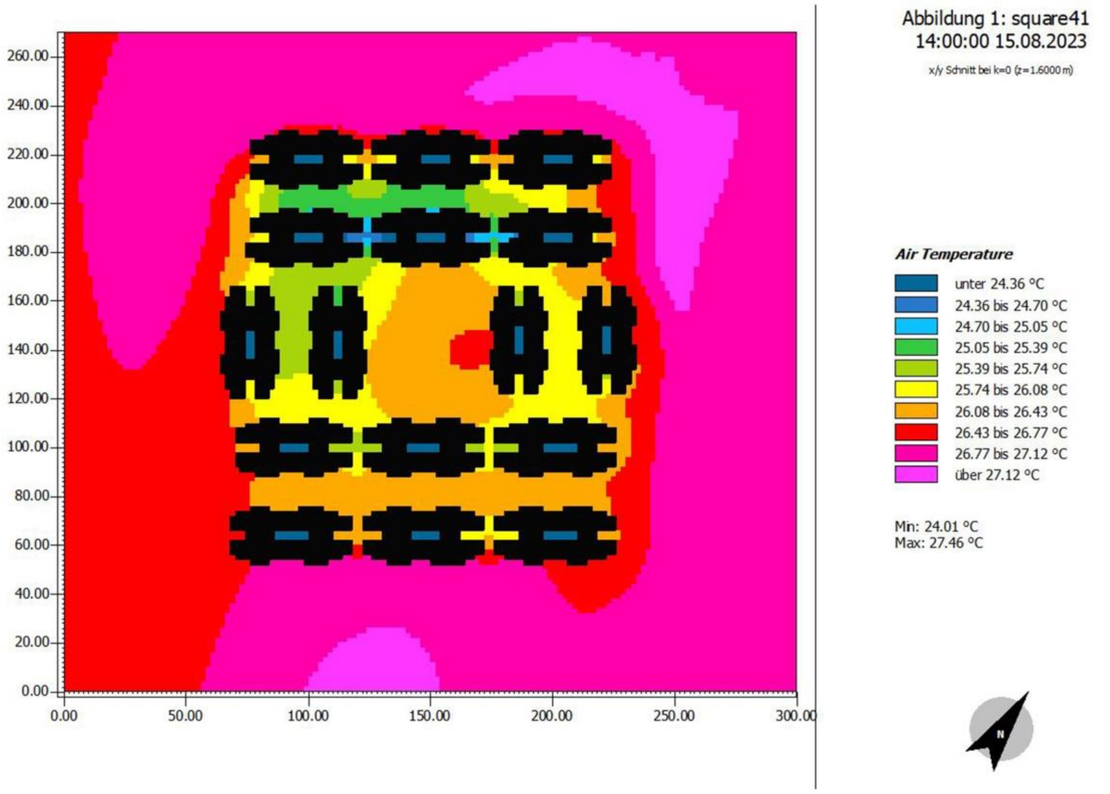


Figure 29. ENVI-met result of air temperature at 2 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 3.5

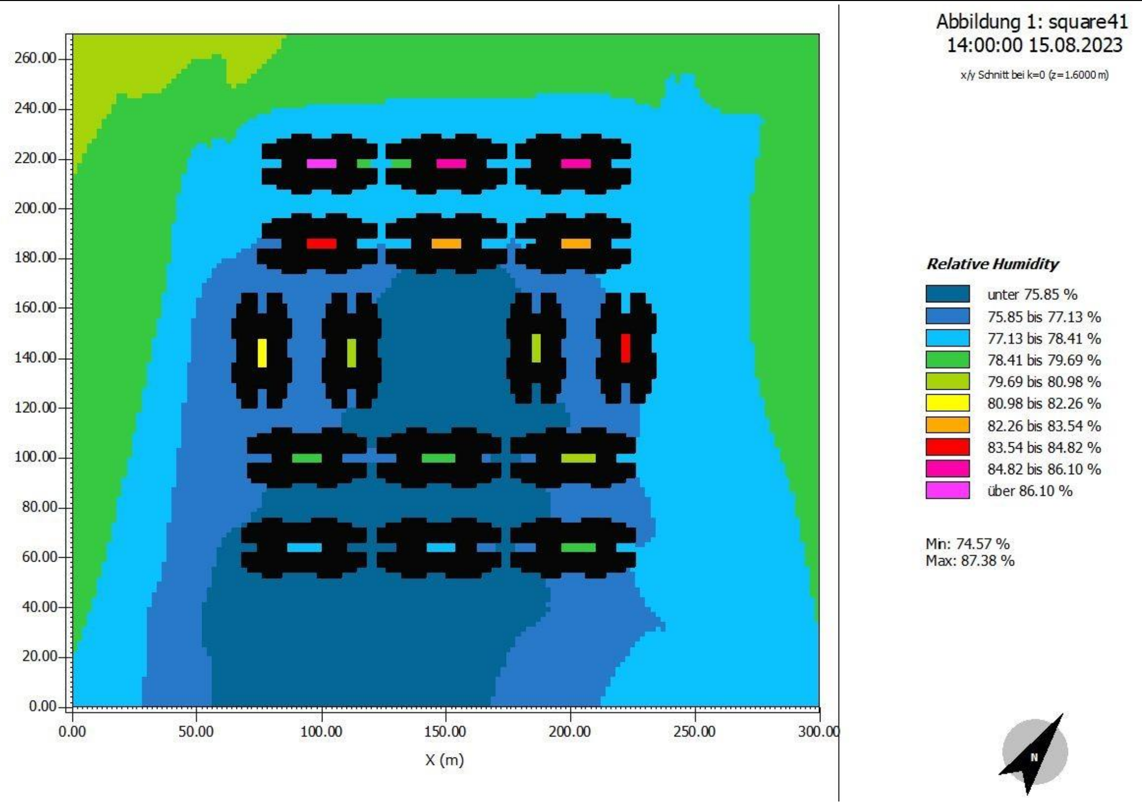
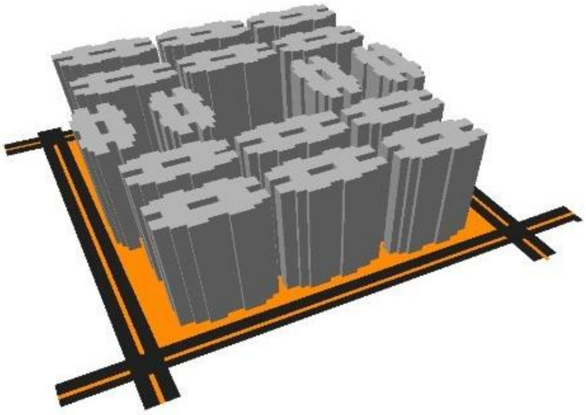


Figure 30. ENVI-met result of relative humidity at 2 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 3.5

H/W =4.5



ENVI-met result

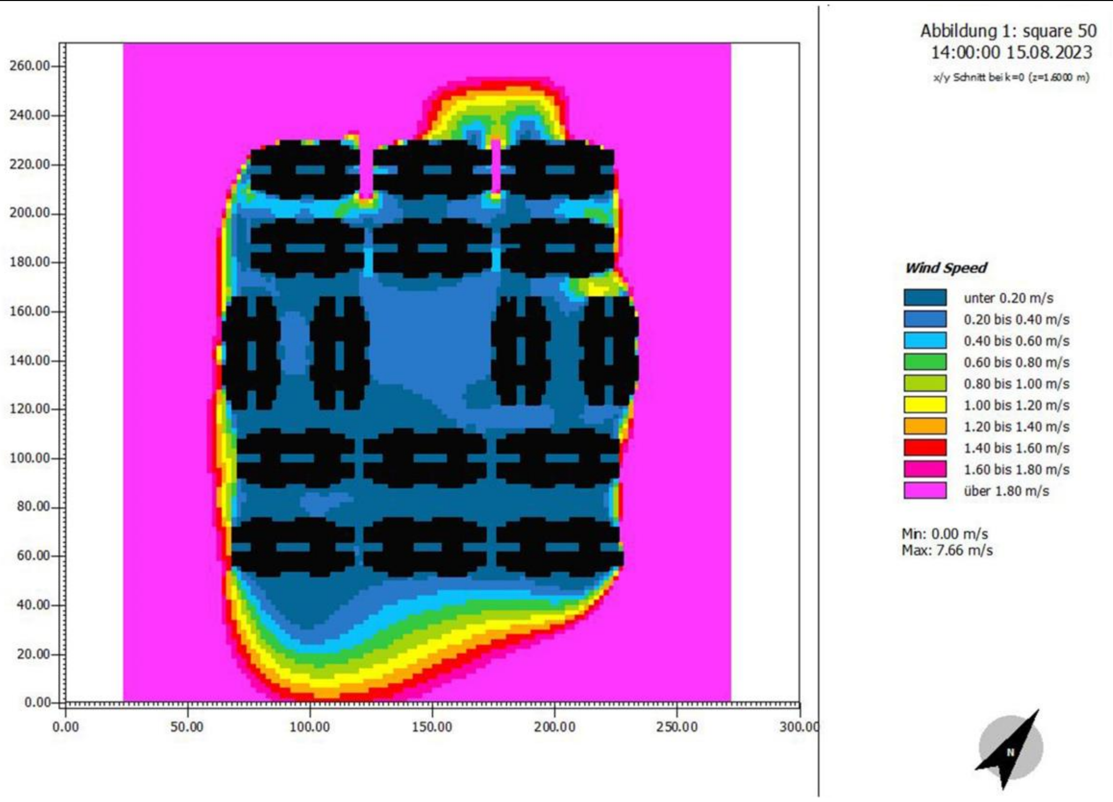


Figure 31. ENVI-met result of wind flow at 2 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 4.5

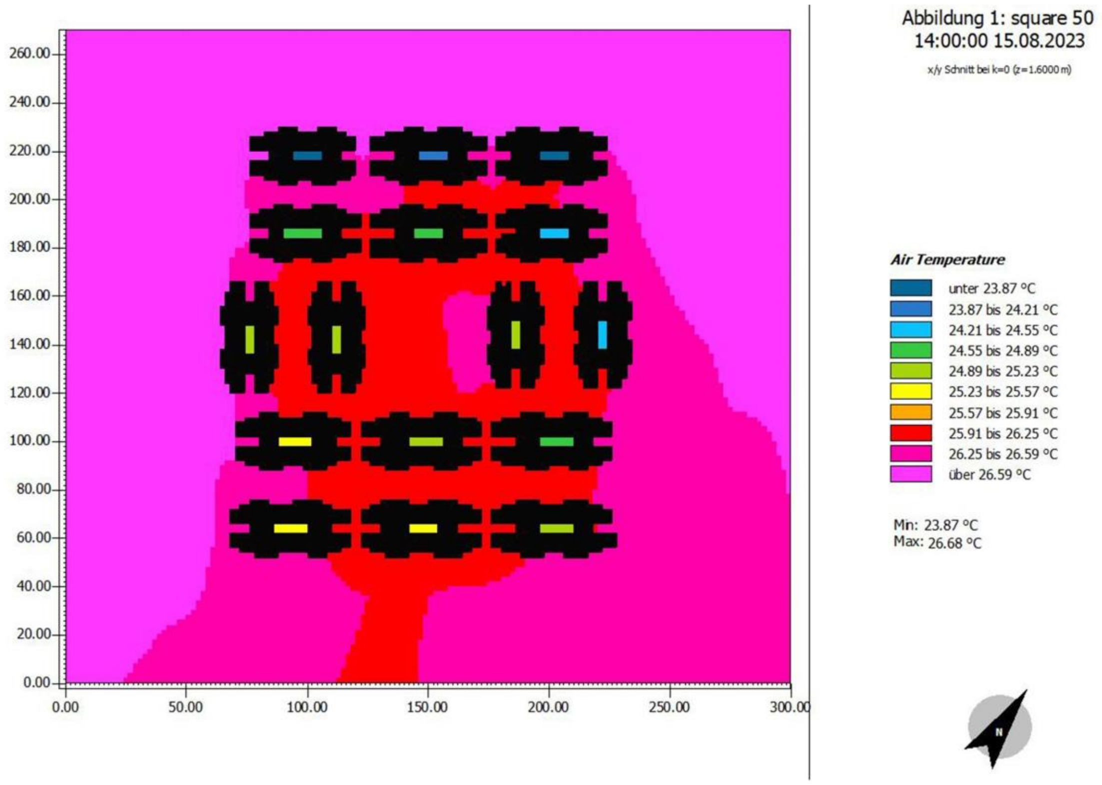


Figure 32. ENVI-met result of air temperature at 2 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 4.5

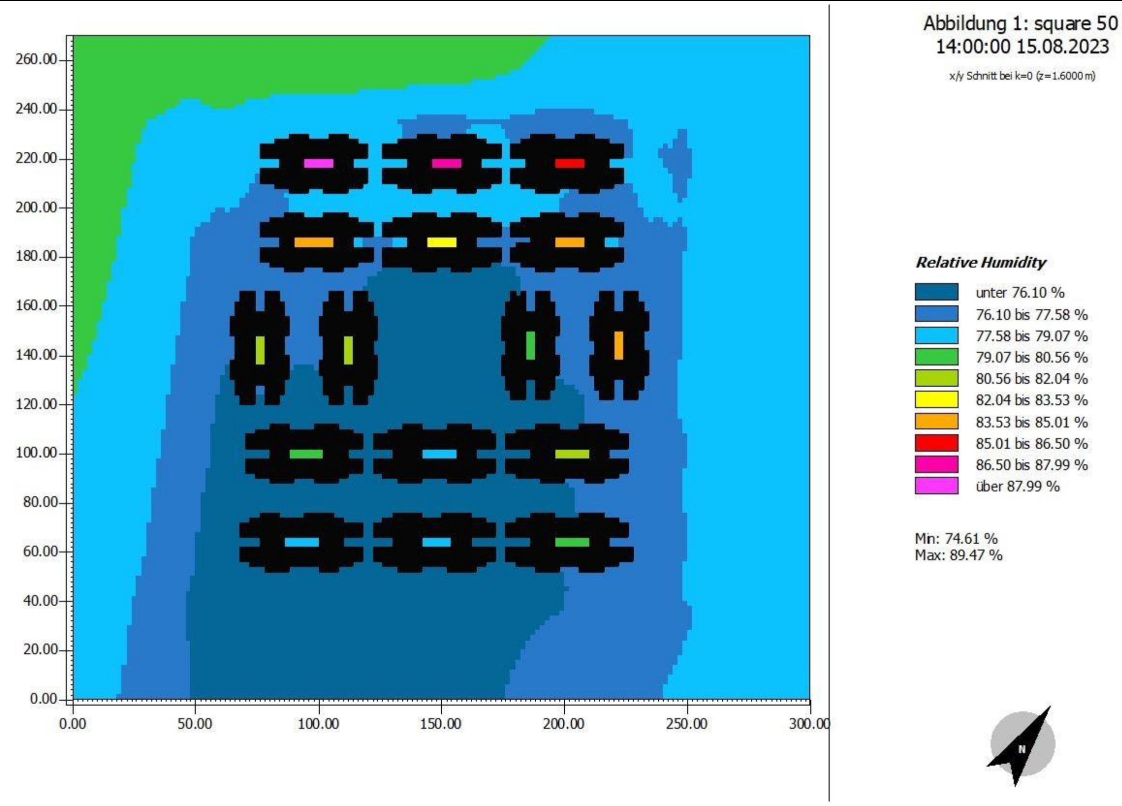


Figure 33. ENVI-met result of relative humidity at 2 p.m. on August 15 for case Bashayer Al-Khair (5) at (H/W) equal 4.5

Table 6. Comparative the Wind Flow, air temperature and relative humidity between case 1 on (H/W) equal 1.5, case 2 at (H/W) equal 2.5, case 3 at (H/W) equal 3.5 and case 4 at (H/W) equal 4.5 on August 15. by the researcher based on the data outputted from ENVI-met

Scenarios	**Wind speed**	**Air Temperature**			**Relative Humidity**		
	Average	Max	Min	avg	Min	Max	avg
H / W = 1.5	2.25	30.60	27.40	29	74.27	79.73	77
H / W = 2.5	3.12	29.23	26.28	27.7	74.55	81.92	78
H / W = 3.5	3.7	27.46	24.01	25.7	74.57	87.38	80.9
H / W = 4.5	3.83	26.7	23.9	25.3	74.61	89.47	82

Overall, the results demonstrate that higher H/W ratios contribute to increased wind speed and reduced peak temperatures, enhancing outdoor thermal comfort, but may also increase relative humidity within the urban canyon. These findings highlight the importance of optimizing H/W ratios in high-rise residential planning to balance shading, ventilation, and thermal comfort.

4. Discussion

The research results can be discussed in three areas: Wind Flow, Atmospheric Temperature, and Humidity Level in open spaces, in accordance with the classification detailed in the results section and consistent with the study's aims. The study highlighted the critical connection between urban morphology and outdoor thermal comfort. The square courtyard typology's compact design showed superior performance in parameters as the optimal model for high-rise affordable housing in hot, humid climates like Alexandria, including Wind Flow. Despite being functional, the rectangular and linear configurations exhibited thermal comfort metrics that were less optimal.

The simulation results of the three scenarios—rectangular courtyard (Case A), linear block (Case B), and square courtyard (Case C)—highlight significant differences in wind flow, air temperature, and relative humidity, all of which play a decisive role in determining outdoor thermal comfort (OTC)

In terms of **wind flow**, the square courtyard exhibited the highest average wind speed (3.7 m/s), followed by the linear block (3.5 m/s), while the rectangular courtyard recorded the lowest value (3.4 m/s) (Figure 11, Figure 15, Figure 19). The enhanced airflow in the square courtyard can be attributed to its compact geometry, which reduces obstruction and promotes circulation. Conversely, the elongated configuration of the rectangular courtyard restricts ventilation efficiency, thereby reducing its cooling potential (Figure 34).

Regarding **air temperature**, the linear block scenario demonstrated the highest average (28.6 ℃) and maximum (30.26 ℃) values, reflecting the heat accumulation effect commonly associated with elongated, compact forms of high-density housing (FAR = 8.15). By contrast, the square courtyard achieved the lowest average (25.7 ℃) and minimum (24.01 ℃) temperatures, confirming its superior capacity to mitigate heat stress through shading and ventilation. The rectangular courtyard displayed intermediate values (average 26.8 ℃), balancing between moderate solar exposure and limited ventilation (Figure 35).

For **relative humidity**, values remained consistently high across all scenarios, reflecting the prevailing hot-humid Mediterranean climate of Alexandria. However, subtle variations were observed: the linear block reached the highest average humidity (82%), likely due to reduced wind penetration and heat storage, while the rectangular and square courtyards reported slightly lower averages (80.7% and 80.9% respectively) (Figure 13, Figure 14, Figure 21).

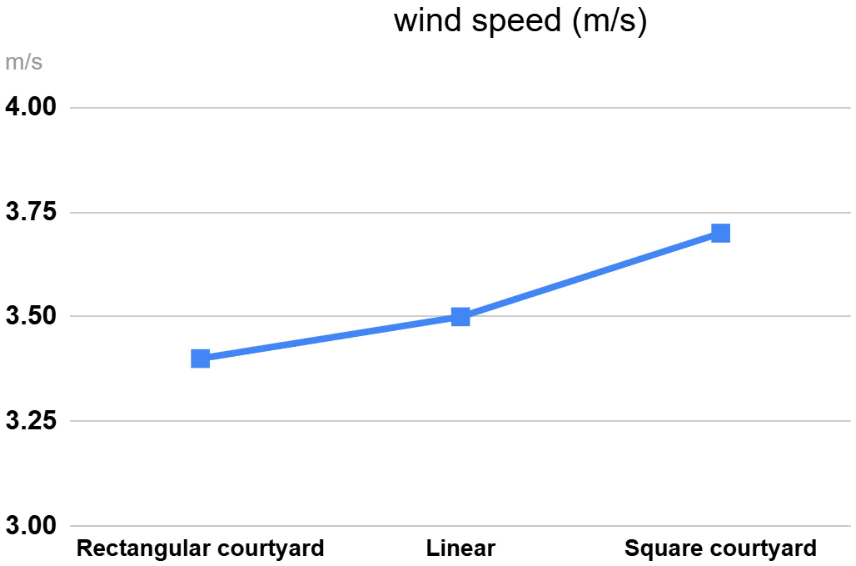


Figure 34. Wind speed for case A rectangular courtyard, case B linear and case C square courtyard on August 15 (By Author)

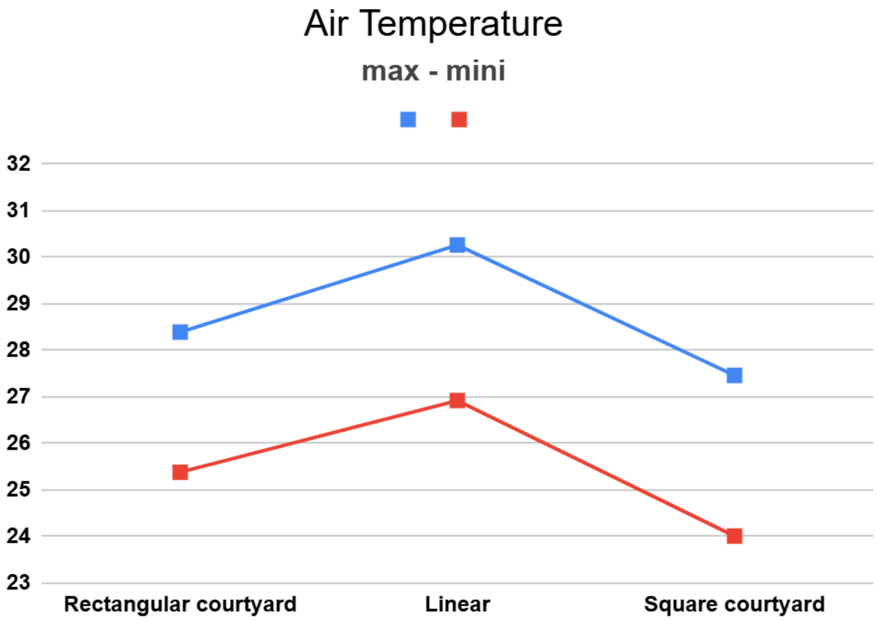


Figure 35. Min and max air temperature for case A rectangular courtyard, case B linear and case C square courtyard on August 15 (By Author)

Taken together, the findings demonstrate that urban morphology directly influences microclimatic performance. The square courtyard, with its balanced floor area ratio (7.66) and compact spatial arrangement, provided the most favourable conditions across all parameters, achieving lower air temperatures, enhanced wind speeds, and controlled humidity. In contrast, the linear configuration, despite higher density, performed least effectively due to its heat accumulation and reduced ventilation capacity.

These results underscore the importance of integrating morphological parameters—such as typology, floor area ratio, and block orientation—into the planning of affordable housing projects to enhance thermal comfort and liveability in hot-humid climates.

A comparative analysis of the four simulated cases (H/W = 1.5, 2.5, 3.5, and 4.5) highlights the significant influence of canyon aspect ratio on wind flow, air temperature, and relative humidity in outdoor spaces.

In terms of wind speed, the results indicate a progressive increase as the H/W ratio rises. The lowest average wind speed (2.25 m/s) was recorded in the shallow canyon (H/W = 1.5), while the deepest canyon (H/W = 4.5) achieved the highest average wind speed of 3.83 m/s. This suggests that higher aspect ratios facilitate greater airflow circulation, reducing stagnation zones and enhancing ventilation potential (Figure 36).

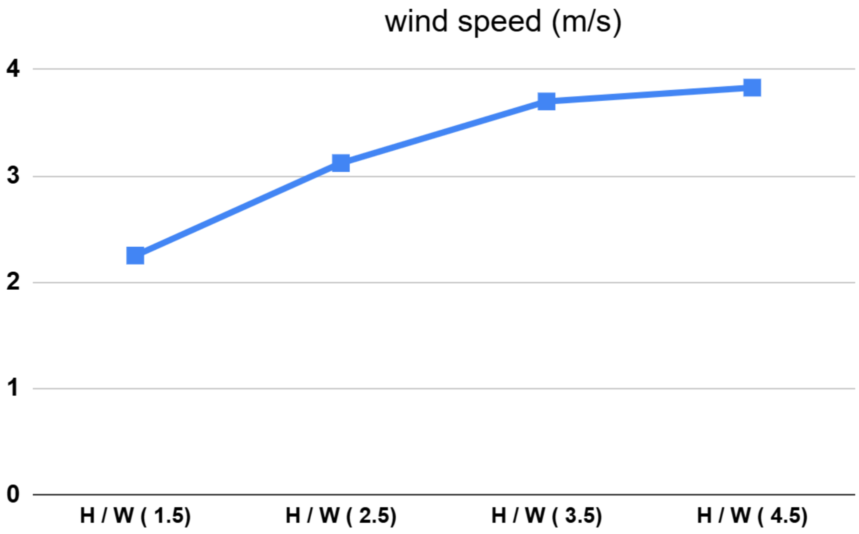


Figure 36. Wind speed for case 1 at (H/W) equal 1.5, case 2 at (H/W) equal 2.5, case 3 at (H/W) equal 3.5 and case 4 at (H/W) equal 4.5 on August 15. (By Author)

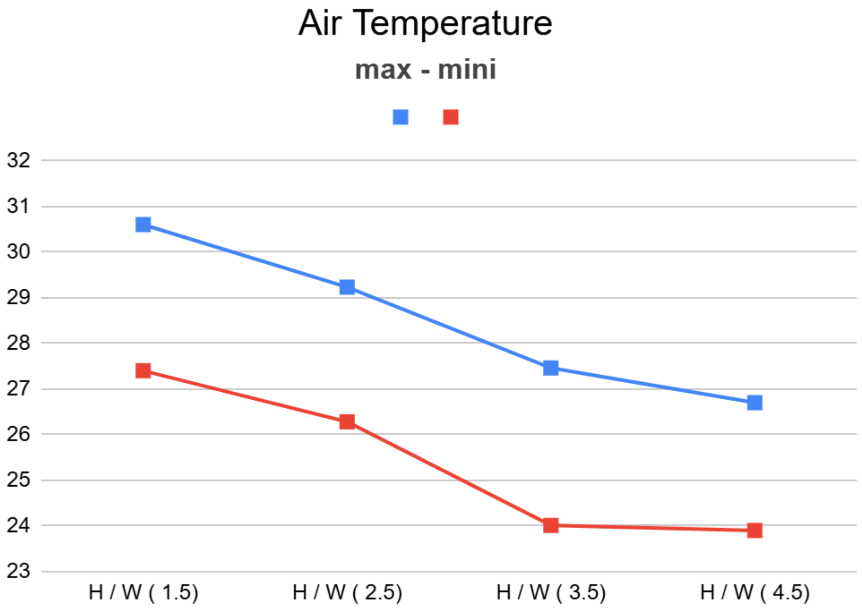


Figure 37. Air temperature for case 1 at (H/W) equal 1.5, case 2 at (H/W) equal 2.5, case 3 at (H/W) equal 3.5 and case 4 at (H/W) equal 4.5 on August 15. (By Author)

With respect to <u>air temperature</u>, the shallow canyon (H/W = 1.5) recorded the highest average value of 29 ℃, while the deep canyon (H/W = 4.5) experienced the lowest at 25.3 ℃. This inverse relationship between H/W ratio and ambient temperature can be attributed to increased shading in deeper canyons, which reduces solar gains and lowers heat accumulation (Figure 37).

For <u>relative humidity</u>, values show an incremental rise with increasing H/W. Case 1 (H/W = 1.5) recorded the lowest average relative humidity (77%), whereas Case 4 (H/W = 4.5) exhibited the highest (82%). This outcome reflects the combined effect of reduced temperature and limited direct solar radiation in deeper canyons, which enhances moisture retention in the microclimate.

Overall, the findings reveal that higher H/W ratios (3.5–4.5) provide a more favourable balance between enhanced ventilation and reduced thermal stress, particularly in hot-humid contexts such as Alexandria. However, the increase in relative humidity at higher ratios raises important considerations for thermal comfort indices, as elevated moisture levels may offset some of the cooling benefits of shading and airflow.

As the height-to-width ratio (H/W) increases, air temperature decreases while wind speed rises, thereby enhancing outdoor thermal comfort. The simulation results indicate that the average air temperature dropped from 29.0 ℃ (at H/W = 1.5 to 25.3 ℃ (at H/W = 4.5), representing a reduction of 3.7 ℃. Simultaneously, the average wind speed increased from 2.25 m/s to 3.83 m/s, marking an improvement of 1.58 m/s.

In contrast, relative humidity values exhibited a gradual increase with higher H/W ratios, rising from 77% at H/W = 1.5 to 82% at H/W = 4.5. While this increase may suggest higher moisture content in the microclimate, the concurrent enhancement of wind circulation plays a critical role in offsetting humidity discomfort, resulting in improved thermal comfort conditions overall.

These variations highlight the strong influence of urban geometry on microclimatic conditions and emphasize the role of compact, vertically oriented forms in mitigating thermal stress and promoting outdoor liveability in hot-humid climates.

This phenomenon aligns with the Venturi effect, where airflow accelerates through constrained passages, improving outdoor thermal comfort despite slightly higher relative humidity levels.

These findings are in line with previous studies, which confirmed that deeper canyons (higher H/W) provide more shading and cooler microclimates, while also facilitating stronger wind flows due to corridor effects [38].

The results are particularly relevant to hot-humid climates such as Alexandria, where mitigating heat stress through urban form is essential. The increase in wind speed combined with reduced air temperature at higher H/W ratios demonstrates a viable passive design strategy for enhancing outdoor thermal comfort in dense affordable housing developments.

5. Conclusions

This study investigated the influence of urban form on outdoor thermal comfort (OTC) in high-rise affordable housing in Alexandria, Egypt, using ENVI-met simulations during the summer of 2023. Three neighbourhood geometries—rectangular courtyard, linear, and square courtyard—were analysed with varying densities and height-to-width (H/W) ratios.

The key findings are as follows:

The square courtyard typology provides the most favourable OTC conditions, with improved ventilation and cooler air temperatures compared to other forms.

Increasing the H/W ratio from 1.5 to 4.5 reduces average air temperature by approximately 3-4 ℃, increases wind speed from 2.25 to 3.83 m/s, and moderately raises relative humidity from 77% to 82%.

Density and inter-block spacing significantly influence microclimatic conditions, indicating that compact yet well-ventilated configurations enhance thermal comfort.

The study confirms that urban morphology—including building layout, height-to-width ratio, and block spacing—plays a critical role in regulating microclimatic conditions in high-density housing.

5.1. Recommendations

<u>Impact:</u>

- Adopt the square courtyard urban form in future affordable housing projects to enhance outdoor thermal comfort and support sustainable urban development.
- Optimize H/W ratios and inter-block spacing in high-rise residential planning to improve ventilation and microclimate.
- Incorporate vegetation, building orientation, and material selection to provide comprehensive thermal comfort benefits.
- Redesign aspects to improve resilience to climate change, such as increased shade and enhanced ventilation.

<u>Cost:</u>

- Evaluate the cost-effectiveness of the square courtyard design in other high-density housing projects, balancing energy efficiency and thermal comfort against construction costs.
- Examine alternative building materials (e.g., reflective roofs, thermal mass) to improve energy efficiency and comfort.
- Assess integration of green roofs or vertical gardens for air quality, heat mitigation, and aesthetics.

<u>Feasibility:</u>

- Conduct long-term environmental monitoring in different courtyard typologies to validate simulation results.

- Perform surveys or interviews with residents to capture qualitative perceptions of thermal comfort and air quality.
- Investigate smart building technologies and IoT solutions for real-time monitoring and adaptive control of indoor and outdoor conditions.
- Compare Alexandria's housing typologies with similar urban environments in other hot-humid climates to assess generalizability.

REFERENCES

[1] Ali-Toudert F., Mayer H., "Urban geometry as a climate adaptation strategy for enhancing outdoor thermal comfort in a hot desert climate," Frontiers of Architectural Research, vol. 14, no. 2, pp. 525–544, 2025. DOI: 10.1016/j.foar.2024.08.004.

[2] Meng Y., Hao Y., Que Y., Ren J., Liu Y., "Multi-Objective Optimization of Morphology in High-Rise Residential Areas for Outdoor Thermal Comfort in Yulin City, Northwest China," Buildings, vol. 14, no. 6, p. 1688, 2024. DOI: 10.3390/buildings14061688.

[3] Mazzetto S., El Khoury R., Malkoun J., "Promoting sustainable communities through affordable housing: A case study of Beirut, Lebanon," Frontiers in Sustainable Cities, vol. 6, 2024. DOI: 10.3389/frsc.2024.1308618.

[4] Upreti M., Saikia P., Lal P., Kumar A., "Major challenges in the urbanizing world and role of earth observations for livable cities," in Earth Observation in Urban Monitoring, Elsevier, 2024, pp. 23–52. DOI: 10.1016/B978-0-323-99164-3.00002-1.

[5] Li X., Liu W., "Effects of urban morphology on wind flow and outdoor thermal comfort: CFD simulation and field measurements," Building and Environment, vol. 216, p. 108910, 2022. DOI: 10.1016/j.buildenv.2022.108910.

[6] Dabaieh M., Maguid D., El Mahdy D., Al Hegazi S., "Climate change adaptation at the margins: The case of Cairo, Egypt," Cities, vol. 154, p. 105390, 2024. DOI: 10.1016/j.cities.2024.105390.

[7] Silva R., Oliveira P., Lima M., "Urban canyon geometry and microclimate: Lessons from Campinas, Brazil," Building and Environment, vol. 197, p. 108960, 2021. DOI: 10.1016/j.buildenv.2021.108960.

[8] Chen Y., Li X., Zhang H., "Canyon aspect ratio and airflow enhancement in high-rise neighborhoods: A study in Taiyuan, China," Sustainable Cities and Society, vol. 76, p. 103444, 2022. DOI: 10.1016/j.scs.2022.103444.

[9] Wang L., Zhou Q., "Effects of tree spacing and street geometry on pedestrian thermal comfort in urban environments," Urban Climate, vol. 40, p. 101035, 2021. DOI: 10.1016/j.uclim.2021.101035.

[10] Alzoubi H., Taha H., "Optimizing urban canyon aspect ratios for thermal comfort and energy savings in Irbid, Jordan," Energy and Buildings, vol. 250, p. 111279, 2021. DOI: 10.1016/j.enbuild.2021.111279.

[11] Ben Salah M., Trabelsi S., "Residential block morphology and solar gain: A comparative study in Tunis," Journal of Building Performance, vol. 13, no. 2, pp. 55–69, 2022. DOI: 10.1080/24744731.2022.2034567.

[12] Santamouris M., "Ventilation and urban microclimate: Impacts on outdoor thermal comfort," Renewable and Sustainable Energy Reviews, vol. 82, pp. 3321–3336, 2018. DOI: 10.1016/j.rser.2017.10.086.

[13] Emmanuel R., Fernando H.J.S., "Urban heat island and the influence of wind speed on pedestrian comfort," Building and Environment, vol. 44, pp. 155–167, 2009. DOI: 10.1016/j.buildenv.2008.02.014.

[14] Briegel F., Wehrle J., Schindler D., Christen A., "High resolution multi scaling of outdoor human thermal comfort and its intra urban variability based on machine learning," Geosci. Model Dev., vol. 17, pp. 1667–1688, 2024. DOI: 10.5194/gmd-17-1667-2024.

[15] Malekzadeh M., Loveday D. L., "Towards the integrated thermal simulation of indoor and outdoor building spaces," Proceedings of the Conference: Air Conditioning and the Low Carbon Cooling Challenge, Cumberland Lodge, Windsor, UK, pp. 27–29, 2008.

[16] Vartholomaios A., "A parametric sensitivity analysis of the influence of urban form on domestic energy consumption for heating and cooling in a Mediterranean city," Sustainable Cities and Society, vol. 28, pp. 135–145, 2017. DOI: 10.1016/j.scs.2016.09.006.

[17] Nikolopoulou M., Steemers K., "Thermal comfort and psychological adaptation as a guide for designing urban spaces," Energy and Buildings, vol. 35, no. 1, pp. 95–101, 2003. DOI: 10.1016/S0378-7788(02)00084-1.

[18] Johansson E., Yahia M. W., Arroyo I., "The influence of urban planning variables on outdoor thermal comfort: A case study in a hot, dry climate," International Journal of Biometeorology, vol. 62, no. 7, pp. 1139–1152, 2018. DOI: 10.1007/s00484-017-1329-xNo.7, pp.1139–1152, 2018.

[19] Zhang J., Heng C. K., Malone-Lee L. C., Hii D. J. C., Janssen P., Leung K. S., Tan B. K., "Evaluating environmental implications of density: A comparative case study on the relationship between density, urban block typology and sky exposure," Automation in Construction, vol. 22, pp. 90–101, 2012. DOI: 10.1016/j.autcon.2011.06.011.

[20] Taleghani M., Kleerekoper L., Tenpierik M., van den Dobbelsteen A., "Outdoor thermal comfort within five different urban forms in the Netherlands," Building and Environment, vol. 83, pp. 65–78, 2015. DOI: 10.1016/j.buildenv.2014.03.014.

[21] Srivanit M., Jareemit D., "Modeling the influences of layouts of residential townhouses and tree-planting patterns on outdoor thermal comfort in Bangkok suburb," Journal of Building Engineering, vol. 30, p. 101262, 2020. DOI: 10.1016/j.jobe.2020.101262.

[22] Lai D., Lian Z., Liu W., Guo C., Liu W., Liu K., Chen Q., "A comprehensive review of thermal comfort studies in urban open spaces," Science of the Total Environment, vol. 742, p. 140092, 2020. DOI: 10.1016/j.scitotenv.2020.140092.

[23] Hafez N. M., Kamel R. R., Elsherif D. M., Nasreldin R.,

"Realization of the key aspects of the right to adequate housing in affordable housing programs in Egypt," Journal of Engineering and Applied Science, vol. 68, pp. 1–14, 2021. DOI: 10.1186/s44147-021-00018-8.

[24] Achour-Younsi S., Kharrat F., "Outdoor thermal comfort: Impact of the geometry of an urban street canyon in a Mediterranean subtropical climate — Case study Tunis, Tunisia," Procedia – Social and Behavioral Sciences, vol. 216, pp. 689–700, 2016. DOI: 10.1016/j.sbspro.2015.12.062.

[25] Chen Y., Li X., Zhang H., "Canyon aspect ratio and airflow enhancement in high-rise neighborhoods: A study in Taiyuan, China," Sustainable Cities and Society, vol. 76, p. 103444, 2022. DOI: 10.1016/j.scs.2022.103444.

[26] Climate Consultant. (Version 6.0) [Computer software]. http://climateconsultant.org

[27] Sutherland J., Peet A. H., Soulsby R. L., "Evaluating the performance of morphological models," Coastal Engineering, vol. 51, no. 8–9, pp. 917–939, 2004. DOI: 10.1016/j.coastaleng.2004.07.015.

[28] Lawrence Berkeley National Laboratory, "Climate Consultant 6," Energy Design Tools, Available at: https://www.energy-design-tools.aud.ucla.edu/ (accessed July 12, 2024).

[29] ENVI-MET, "Microclimate simulation software," ENVI-MET, Available at: https://envi-met.com/microclimate-simulation-software/ (accessed July 12, 2024).

[30] Salvati A., Kolokotroni M., "Urban microclimate and climate change impact on the thermal performance and ventilation of multi-family residential buildings," Energy and Buildings, vol. 294, p. 113224, 2023. DOI: 10.1016/j.enbuild.2023.113224.

[31] Egyptian State Information Service, "Bashayer El Kheir Housing Project," 2019. Available at: https://www.sis.gov.eg/Story/190040 (accessed July 12, 2024).

[32] Magdy Y., Elhamy A. A., "Energy Optimization for Affordable Housing via Microclimate and Energy Simulation, Case Study: Bashayer El Kheir 1, Alexandria, Egypt," Future Cities and Environment, vol. 9, no. 1, 2023. DOI: 10.5334/fce.186.

[33] Shafik S., Hemeida F., Sharaby A., "Affordability as an obstacle in the housing development process in Egypt for low-incomes: Case of Bashayer Al-Khair," WIT Transactions on Ecology and the Environment, vol. 241, pp. 297–308, 2020. DOI: 10.2495/SDP200241.

[34] Google Earth, "Qabari, Alexandria." Available at: https://earth.google.com/web/search/qabari+alexandria (accessed July 1, 2025).

[35] EGY Map, "Bashayer El Kheir 5 project." Available at: https://egy-map.com/project/5-مشروع-بشاير-الخير (accessed July 1, 2025).

[36] Presidency of Egypt, "Bashayer El-Kheir Project: First Phase." Available at: https://www.presidency.eg/ar/ (accessed July 1, 2025).

[37] SEE News, "Sisi inaugurates 3rd phase of Bashayer Al-Khair housing project in Alexandria," 2022. Available at: https://see.news/sisi-inaugurates-3rd-phase-of-bashayer-al-khair-housing-project-in-alexandria (accessed July 12, 2025).

[38] Muniz-Gäal, L. P., et al., "Urban geometry and the microclimate of street canyons in Mediterranean climates," Building and Environment, vol. 197, p. 108960, 2020. DOI: 10.1016/j.buildenv.2020.108960.