

# International Journal of Urban Management and Energy Sustainability (IJUMES)

Homepage: <http://www.ijumes.com>



## CASE STUDY RESEARCH PAPER

### CFD-Based Evaluation of Courtyard Proportions on Indoor Air Quality in Hot and Humid Residential Buildings (Case Study: Traditional Houses in Bushehr city, Iran)

Seyed Sajjad Abdoli<sup>1</sup>, Marjan Shahabzadeh<sup>2\*</sup>, Hamid Eskandari<sup>3</sup>

<sup>1</sup> Department of Architecture, Shi.C., Islamic Azad University, Shiraz, Iran

<sup>2</sup> Department of Urban Planning and Architecture, Shi.C., Islamic Azad University, Shiraz, Iran.

<sup>3</sup> Department of Architecture, Yas.C., Yasuj University, Yasuj, Iran

#### ARTICLE INFO

##### Article History:

Received 2025-08-30

Revised 2025-10-09

Accepted 2025-10-19

##### Keywords:

Bushehr City, central courtyard, Design Builder software, Indoor air quality, natural ventilation, residential buildings

#### ABSTRACT

Natural ventilation plays a critical role in improving indoor air quality and reducing energy consumption in residential buildings located in hot and humid climates. Among passive design strategies, the central courtyard has long been recognized as an effective architectural element for enhancing airflow and thermal performance. However, the quantitative influence of courtyard proportions on indoor ventilation efficiency remains insufficiently explored. The data collection method is library-based and field collection using researcher-centered collections. Subsequently, simulation is performed on the model presented in this phase for evaluation based on criteria and indicators obtained from the main variables in the software. After the climatic study of Bushehr city, Design Builder software is used to analyze and simulate the case studies of the research, which includes 6 historical houses: Haj Rais house, Dehdashti house, Golshan House, Tayyeb house, Azin House, and Nozari house in Bushehr city, which were selected based on the 4 criteria of the existence of a central courtyard. The findings of this study show that medium to high aspect ratios, approximately 1 to 2.1, have significant potential to improve ventilation on the first floor compared to the ground floor, provided that the openings are aligned with the prevailing wind of the area and that there are air flow paths through the openings. Ratios lower than 0.7 generally result in less ventilation on the first floor, unless the facade and openings are designed to direct the prevailing wind inward. The results demonstrate that an integrated consideration of courtyard proportions, opening configuration, and wind orientation can substantially improve natural ventilation performance in hot and humid climates. These results provide practical design guidelines for optimizing courtyard-based residential buildings and reducing reliance on mechanical cooling systems.

DOI: [10.22034/ijumes.2025.2073164.1339](https://doi.org/10.22034/ijumes.2025.2073164.1339)

Running Title: CFD-Based Evaluation of Courtyard Proportions on Indoor Air Quality



NUMBER OF REFERENCES

17



NUMBER OF FIGURES

37



NUMBER OF TABLES

04

\*Corresponding Author:

Email: [marjan.shahabzadeh@iauu.ac.ir](mailto:marjan.shahabzadeh@iauu.ac.ir)

Phone: + 987433331878

ORCID: <https://orcid.org/0000-0003-1709-2071>

## INTRODUCTION

Buildings account for a significant part of the total energy consumption in the world, so that according to estimates, the world's energy demand will increase by about 50% between 2018 and 2050 (Lin et al., 2021). However, finding solutions to save energy consumption in this sector has a significant impact on solving numerous human problems in the economic and environmental fields (Gao et al., 2020). Looking at the past architectural pattern in Iranian cities, energy conservation has been considered in various ways. In these cities, the form of buildings is one were among the most important factors that provided the ground for reducing energy consumption. Architects of the past, using their experience and skills and taking into account all the conditions, used methods to balance the environmental conditions within it and improve the quality of life of the residents (Hou et al., 2022). One of these methods was the use of natural resources and energies in order to provide the conditions of comfort inside the building and as a result, reduce the need for fossil fuels in homes (Bai et al., 2023). These people, using different techniques and methods in organizing and constructing spaces, make it possible to use renewable energies such as sunlight, wind, and air humidity for cooling purposes or They provided heating inside the building, and in this way, while providing the comfort conditions of the residents, they created the ground for reducing the need for fossil fuels and thus reducing energy costs.

A large part of the energy consumed in the building is used to create comfortable conditions for the users of the building. However, various factors affect the creation of comfortable conditions, including temperature, humidity, ventilation, the type of activities of the residents, and the type of their clothing. It is one of the most important indicators of creating comfort for residents. Ventilation is created in both natural and artificial forms in the building, in which mechanical equipment is used to move the air in

the building, while the dominant factor in creating natural ventilation is the use of natural wind forces in order to move the airflow (Figueroa-Lopez et al., 2021). In the vernacular architecture of Iran, especially in hot and humid regions, natural ventilation is one of the It is one of the important factors in the design of the building. Because while providing comfort, it will also be effective in reducing energy consumption and costs. The effectiveness of natural ventilation is highly dependent on the design process and is able to provide between 20 and 60 percent of the building's energy requirements (Zoure et al., 2020). In addition to causing heat exchange between the human body and the environment, the air flow in buildings has a great impact on the feeling of thermal comfort. There are different elements and components in buildings that can affect the natural ventilation in the building. One of these elements, which was also widely used in the Iranian architecture of the past, is the "central courtyard". The courtyard is one of the most important elements of the Iranian architecture of the past, which, in addition to its importance in organizing other spaces around it, plays a significant role in the use of natural energy resources in the house (Wen et al., 2023, Hussein et al., 2022). From an environmental perspective, The central courtyard as an efficient and responsive device, in addition to doing its duty in protecting the residents from unfavorable weather and environmental conditions in various areas, is known as an efficient solution in increasing energy efficiency and improving the living conditions in the indoor environment. This element is like a passive system in the building, by creating shade and directing the desired flow of air into the interior and preventing The entry of unscented air creates comfortable conditions for residents in different climates (Fine et al., 2022). The use of the central courtyard is one of the most important strategies in order to shade and prevent the sun's radiation into the building in different climates, especially in hot climates (Piselli et al., 2022), while the

role of this element in directing the air flow into the building and increasing ventilation in the indoor space is very important in hot and humid climates (Shen et al., 2025). In fact, the courtyard increases the air flow into the building by changing the climate to microclimate in the middle part of the building (Karyono et al., 2020). In the meantime, extracting the proportions of the yard and its effect on the air flow can help to find the relationship between new designs in buildings (Zune et al., 2021). The yard in buildings with hot and humid climates, while shading the floor and walls of the building, reduces the temperature of the walls and air layers around it, and by creating blinds and natural ventilation, it reduces the air temperature in the yard and consequently improves the thermal conditions in the surrounding spaces (Park et al., 2023). Among them, the physical components of the central courtyard, including the general shape of the courtyard and its proportions, play an important role in improving the quality of air flow in interior spaces (Logue et al., 2012). Since no systematic research has been conducted in the field of investigating and analyzing the function of the central courtyard element in the face of environmental conditions in the houses of hot and humid climates of Iran, the first part of this study will investigate the role of spatial proportions of the central courtyard in improving the ventilation efficiency in the interior spaces of the house in a hot and humid climate. (Lim et al., 2012). Openings are other elements that play an effective role in directing the air flow into the building. Different features of the openings such as the ratio of rain to wall, the form of the opening, and the ratio of the opening to the wind to the back-to-wind are among the most important features of this element that have a great impact on the ventilation pattern inside the building. Accordingly, this present study analyzes the characteristics of the openings of the building in interaction in another part of the building. It deals with the central courtyard and the outside of the building in order to improve

the ventilation flow inside the building.

### *Methodology*

The present study is an analysis in terms of structure, which is considered an applied and developmental research in terms of its main objective, and the exploratory approach of the research can also be noted, considering that previous studies did not address the concept of the direct effect of proportions in a common perspective. The data collection method is library-based and field collection using researcher-centered collections. Subsequently, simulation is performed on the model presented in this phase for evaluation based on criteria and indicators obtained from the main variables in the software. It should be noted that in order to enable comparison and achieve an optimal state, it is necessary to use the characteristics of the sample courtyards, possible states and conditions to develop scenarios, and the proposed scenarios to be simulated in order to identify and introduce the best state of the courtyard proportions. After the climatic study of Bushehr, Design Builder software is used to analyze and simulate the case studies of the research. In this section, Bushehr's climatic data will be simulated in the software environment. The data of this simulation, which is in the form of wind speed, air temperature and relative humidity data in the central courtyard of the house. Regarding the evaluation of the proportions of the central courtyard, by examining the dimensions of the courtyards of the studied samples, 11 scenarios are introduced, which are based on the centrality of the square shape for the base case and 10 other cases with different elongations and the same area and height, covering the dimensions of the existing courtyards and complementing the current spectrum, and are evaluated by modeling in the software and finally the scenarios are selected based on comparative comparison.

## DISCUSSION AND FINDINGS

### Case Study: Bushehr City

Bushehr province has an area of about twenty-seven thousand six hundred and fifty-three square kilometers and is located between twenty-seven degrees and fourteen minutes north latitude and fifty-six minutes to fifty-two degrees and fifty-eight minutes east longitude from the Greenwich meridian. The historical fabric of Bushehr, which is located at the northernmost point of the Bushehr peninsula, has a triangular shape and is connected to the sea on two sides (east, west and north) and to the land on one side (south). This fabric has an area of about 40 hectares and includes 1,000 plaques. The spatial scope of the research includes the neighborhoods of Bushehr city, focusing on area 1, located in Bushehr province, which includes 6 historical houses; Haj Rais house, Dehdashti house, Golshan House, Tayyeb house, Azin House and Nozari house in Bushehr city, which were selected based on the four criteria of the existence of a central courtyard, the use of traditional materials and architecture, and common details, the following historical precedents were selected (Fig. 1)

Although the coastal areas of the Persian Gulf, including the coasts of Bushehr province, are located in a temperate zone and should, in principle, have four seasons, it is clear from the study of meteorological documents and statistics that there are practically no more than two seasons in this region per year: one is a relatively cool winter including the months of December, January and February and the other is a hot summer including the rest of the months of the year. The autumn and spring seasons of the Persian Gulf coasts, including Bushehr province, are usually fleeting, short and unremarkable. In general, the general characteristics of the Persian Gulf coasts can be summarized as follows: high temperatures throughout the year, especially in summer, which, with increasing humidity, causes a humid climate; little rainfall, which results in barren lands; small temperature differences between day and night, very little vegetation growth and almost vertical sunlight in spring and summer (Ghobadian, 2013:90). The atmospheric elements that are usually considered in climatology discussions include heat, air pressure, humidity, wind, and rain, each of which is discussed below. (Tab. 1 and 2)

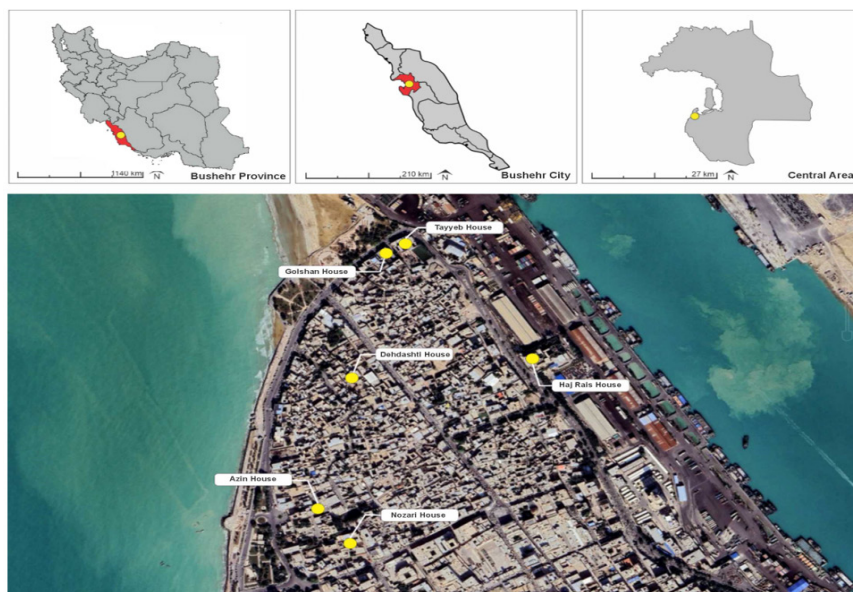
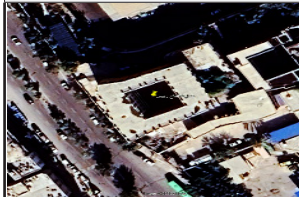
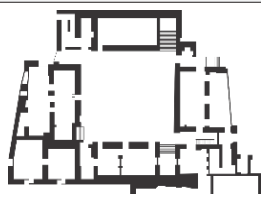



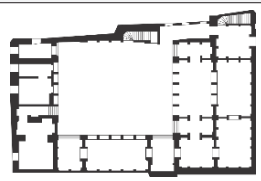









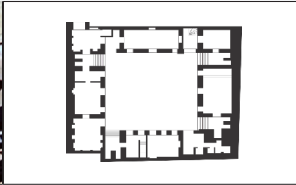



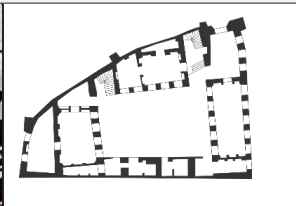
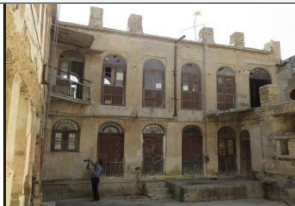


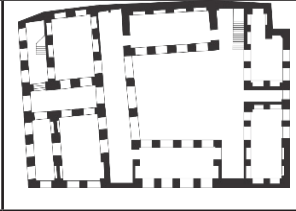


Figure 1: Location of selected houses in the historical area of Bushehr city

**Table 2:** Introduction to the historical houses studied in Bushehr city

Month	Rel Humidity	Direct Norm Rad	Diffuse Rad	Wind Speed	Wind Direction	Air Temperature
	Avg Daily	Avg Daily	Avg Daily	Avg Daily	Avg Daily	Avg Daily
	percent	(Wh/sq.m)	(Wh/sq.m)	ms	degrees	degrees
1	62.34	258.77	236.62	2.19	107.22	17.8
2	67.18	233.67	286.09	2.34	131.29	18.6
3	65.27	276.76	246.44	3.20	128.43	24.8
4	62.70	222.19	348.38	2.43	108.00	26.3
5	64.57	220.43	353.68	3.34	126.90	31
6	62.50	289.61	274.84	2.87	131.25	32.2
7	66.56	218.75	280.77	3.68	130.24	34.6
8	71.59	263.94	274.12	4.13	135.32	33.4
9	67.53	234.94	309.11	3.22	143.50	32.2
10	66.12	233.38	295.09	1.56	68.43	28.4
11	60.08	214.61	251.75	2.10	123.63	24.5
12	66.05	224.41	228.35	2.75	144.63	18.7

**Table 2:** Introduction to the historical houses studied in Bushehr city

Location	Plan	Images	
Haj Rais House (Qajar Period)			
			
Dehdashti House (Qajar Period)			
			
Golshan House (Qajar Period)			
			

Location	Plan	Images	
Tayyeb House (Qajar Period)			
			
Azin House (Qajar Period)			
			
Nozari House (Qajar Period)			
			

**Table 3:** Characteristics of the central courtyard and the buildings of the selected houses

	Width	Length	hight	Floor	Width to length ratio	Width to height ratio	Angel
Nozari	7.38	10.97	6.5	2	1.49	1	14
Azin	9.14	12.46	6.5	2	1.36	1	20
Tayyeb	13.55	13.78	6.5	2	1.02	1	45
Golshan	11.96	12.71	9.5	3	1.06	1	30
Dehdashti	10.26	12.79	12.5	4	1.25	1	34
Haj Rais	14.9	15.53	9.5	3	1.04	1	28

*Evaluation of case studies*

This study aims to understand the effect of courtyard geometry with openings connected to interior spaces as a passive strategy for improving indoor air quality in central courtyard houses in hot and humid climates. From an architectural perspective, courtyard proportions can direct wind paths, change fluid pressures, and affect the performance of natural ventilation. In hot and humid climates, natural ventilation

and air movement are directly related to surface pressure drops and internal thermal phenomena. This study uses Design Builder modeling and CFD analysis to gain a detailed understanding of how the courtyard shape (L/W), building height, and opening arrangement interact. The secondary objective of this study is to provide design strategies for residential spaces with central courtyards to improve both natural ventilation and thermal-shading performance, while main-

taining spatial aesthetics and usable functionality for residents.


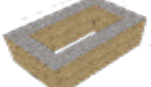



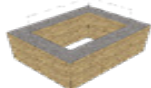

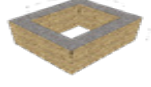



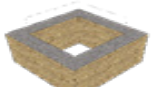

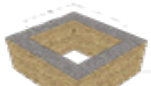







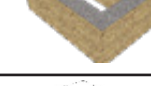
#### *Software validation*

In this study, CFD simulation method was used to analyze case studies, and Design Builder software was used in this regard. In the CFD method, software validation is an essential issue. Accordingly, the experimental data obtained were used to validate the software. This section is defined as the experimental section of the research. Golshan House, as a traditional house with a central courtyard pattern in Bushehr city, was selected as a case study and by visiting it in person during a one-week period in June 2023, data related to ventilation were collected, including wind speed in the courtyard and its surrounding spaces (specifically, the 5-door room located on the northern facade of the building). For this purpose, the Testo i405 Smart Hotwire Anemometer speedometer was used. This device, which is equipped with a wired thermal sensor, can measure low air speeds, connect to a computer and record fluctuations related to air speed, and is capable of measuring air speed in the range of 0 to 30 m/s with an accuracy of  $\pm 1$  and measuring temperature between  $-20$  and  $+60$  degrees Celsius with an accuracy of  $\pm 0.5$  degrees Celsius. Visits are made four times in the morning, noon, evening and night time periods, and finally the average air speed passing through the room in question during a day is extracted. In order to use the data in the software validation section, the speedometer device was installed at a height of 170 cm from the ground and at a distance of 0.5 meters between two room windows, and data was recorded. Case studies in this study were simulated based on the climatic conditions of Bushehr city. According to data from the Meteorological Organization, the average daily temperature in July in Bushehr is 42 degrees Celsius and the average air speed in this month is 1.2 meters per second. In all simulations, a wind angle of zero degrees is assumed

#### *Suggested scenarios for yard proportions*

In this section, the desired scenarios for simulation are first presented in the form of scenarios, and then each scenario is modeled and simulated in the software. It should be noted that the evaluation is carried out in two general parts. First, the scenarios related to the proportions of the central courtyard in traditional Bushehr houses are explained, evaluated, compared, and the desired scenario is selected, and then, in the form of the superior scenario, it will be used as a fixed basis for evaluating the characteristics and conditions of the openings in the main room. In the first scenario category, the height of the walls is considered as a fixed parameter, and the length and width ratios will be considered as independent variables in the evaluation of these scenarios. Regarding the proportions of the courtyards of the samples under study, given that the samples have rectangular and square courtyards with close proportions, the square plan has been considered as a reference sample. Other samples have been formed based on changes in the length to width ratio of the courtyard, which in addition to providing numerical specifications of the case samples (Tab. 4), changes in the shape of the courtyard proportions are observed in the case samples. It is important to note that in determining the case samples, the constant area of the yard in the samples was considered a determining principle, and the longitudinal and transverse proportions of the yard in the samples were selected in such a way that the area of the yard in all samples was constant. Given the constant length of the target room in the samples, the smallest possible aspect in determining the dimensions of the yard was considered to be 5.5 meters (equivalent to the length of the said room). On the other hand, given the constant wind direction in the simulation of the samples, the elongation of the yard in the samples was considered in two states: elongation in the direction of the prevailing wind and elongation perpendicular to the prevailing wind. (Tab. 4)

CFD-Based Evaluation of Courtyard Proportions on Indoor Air Quality

Scenario	Yard width	Yard length	Building height	Length to width ratio	Plan	Volume
1	5.5	11.6	6.5	0.5		
2	6	10.7	6.5	0.6		
3	6.7	9.9	6.5	0.7		
4	7.7	9.3	6.5	0.8		
5	7.5	8.6	6.5	0.9		
6	8	8	6.5	1		
7	8.6	7.5	6.5	1.1		
8	9.3	7.1	6.5	1.3		
9	9.9	6.7	6.5	1.5		
10	10.7	6	6.5	1.8		
11	11.6	5.5	6.5	2.1		

*Evaluation of yard proportions scenarios*

In this section, 11 scenarios proposed in the Design Builder software are modeled and fluid flow conditions are simulated in two cases. The first case is used to evaluate the velocity of air entering the building from the courtyard space between two windows measuring 3 meters by

1.6 meters in the south-facing (central courtyard) and north-facing walls in the target room, and in the second case, the external fluid flow conditions in the space around the building and the space inside the courtyard are simulated in each scenario.

*Scenario 1*

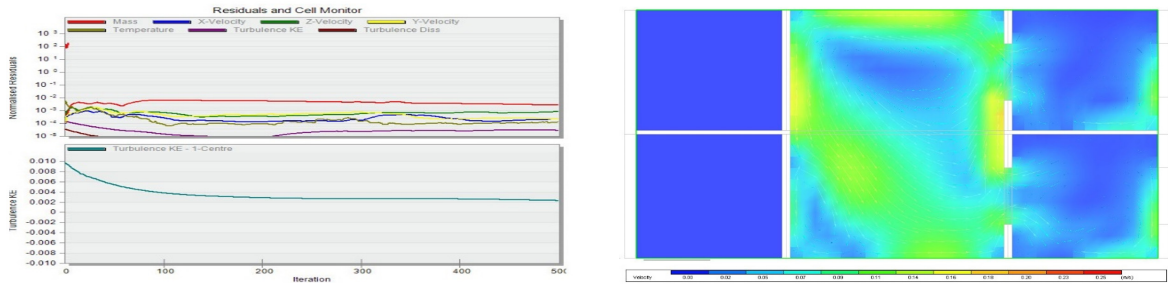


Figure 2 : Air velocity in the yard, ground floor and first floor in the first scenario

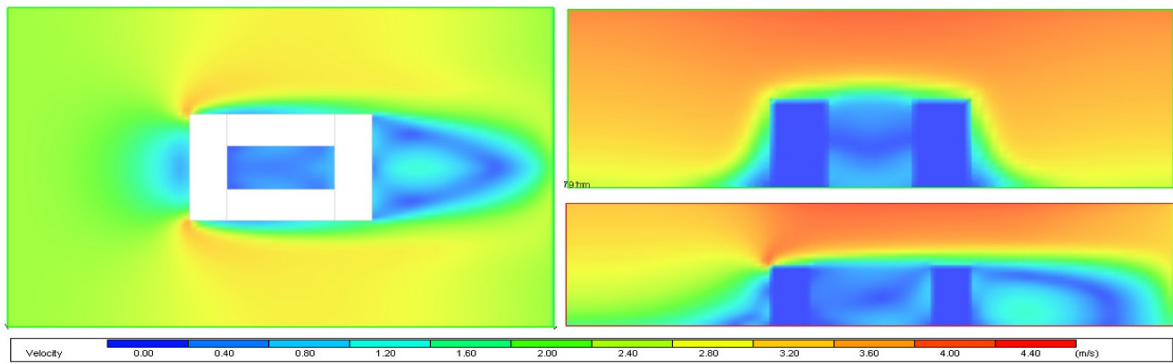


Figure 3: Air velocity in the yard and the space around the building in the first scenario

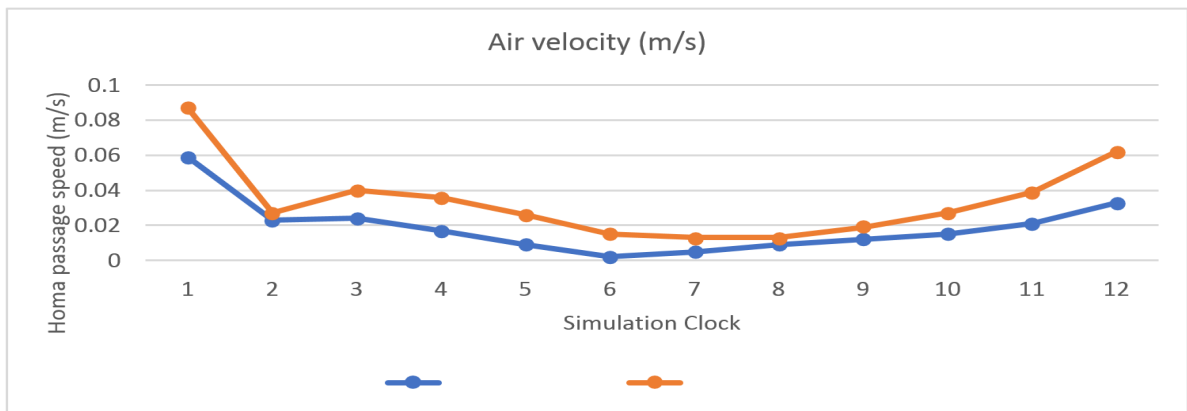


Figure 4: Air velocity between two windows in a room on the ground floor and first floor

Scenario 2

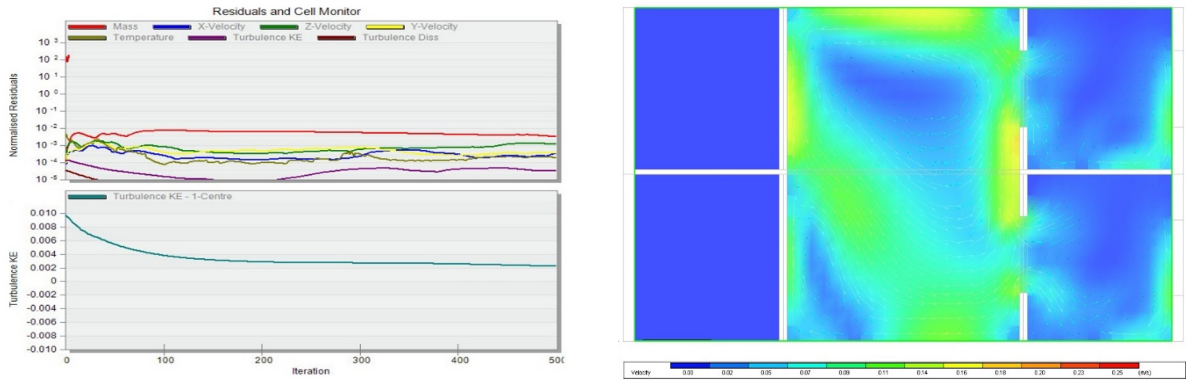


Figure 5: Air velocity in the yard, ground floor and first floor in the second scenario

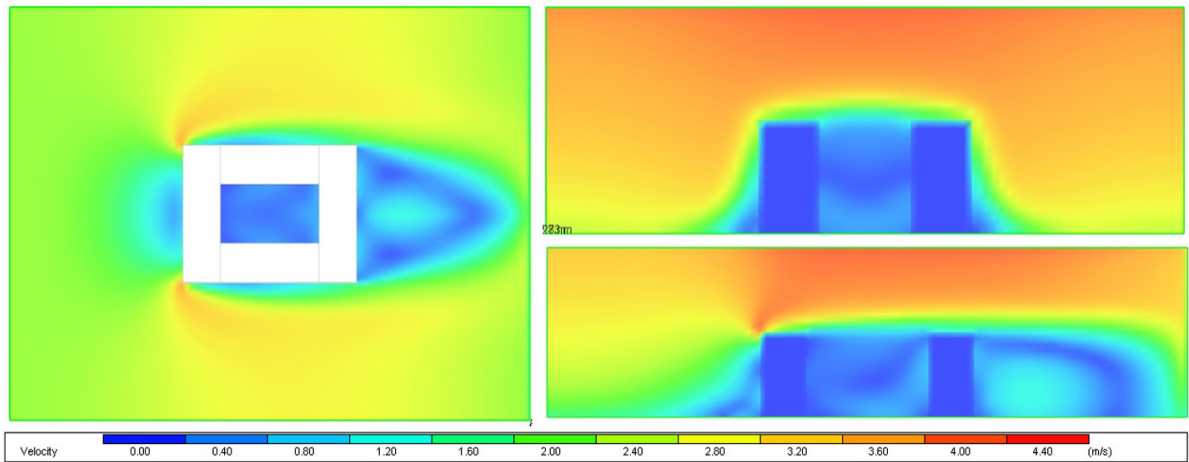


Figure 6: Air velocity in the yard and the space around the building in the second scenario

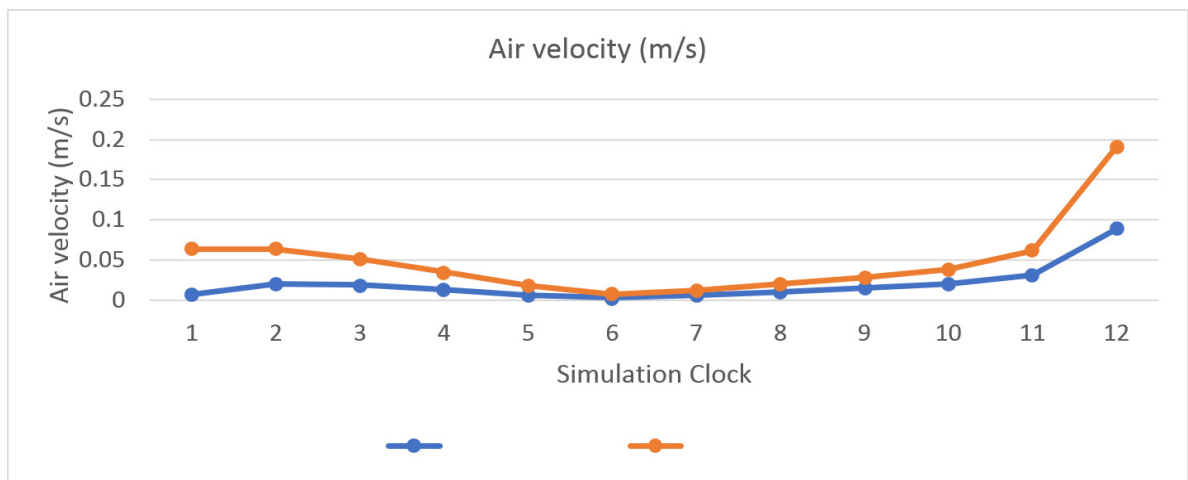


Figure 7: Air velocity between two windows in a room on the ground floor and second floor

Scenario 3

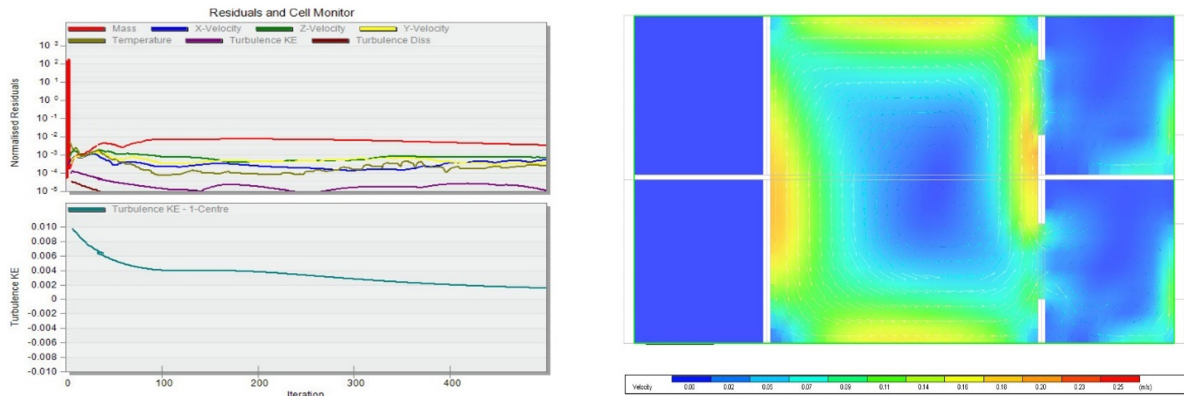


Figure 8: Air velocity in the courtyard, ground floor and first floor in the third scenario

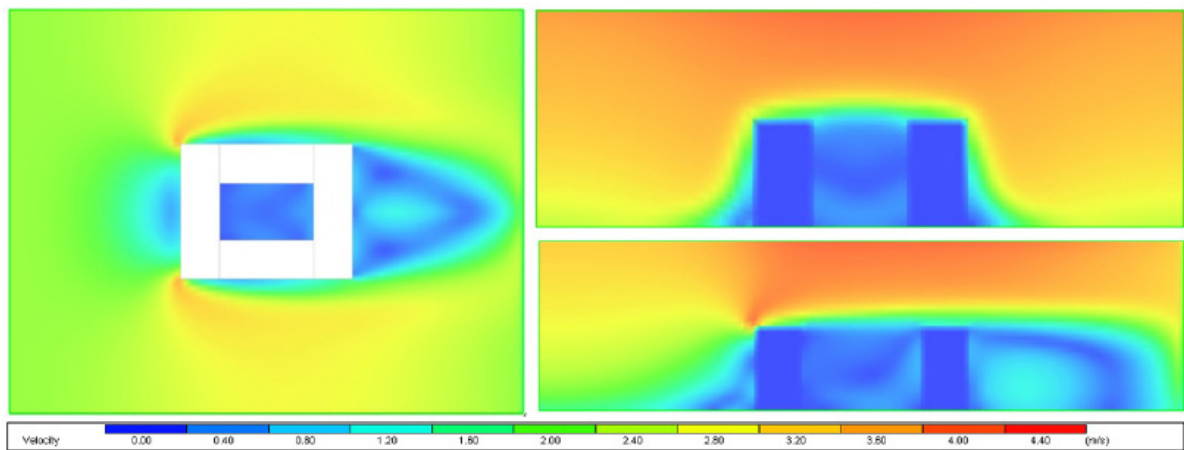


Figure 9: Air velocity in the yard and the space around the building in the third scenario

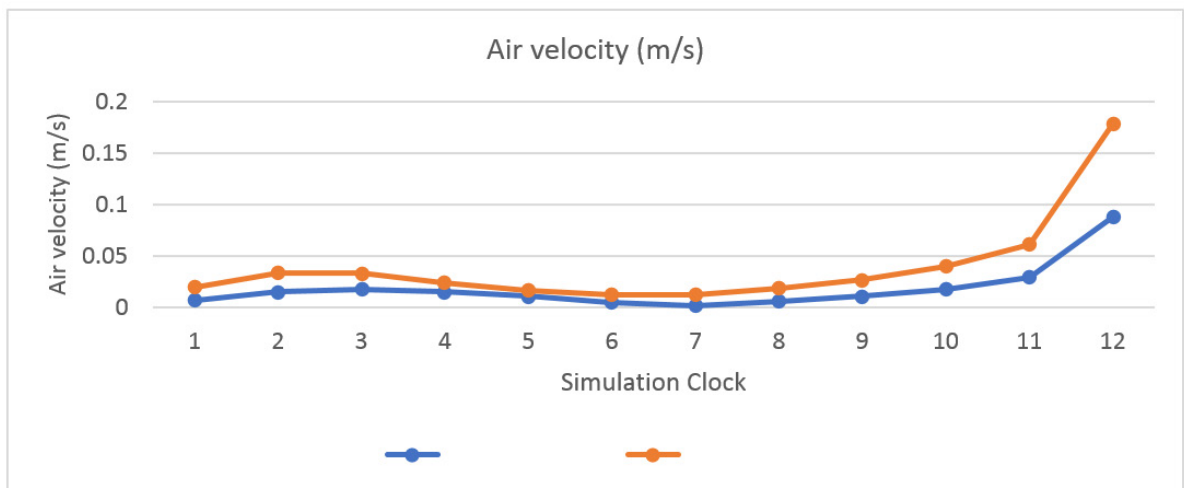


Figure 10: Air flow speed between two windows in a room on the ground floor and the third floor

Scenario 4

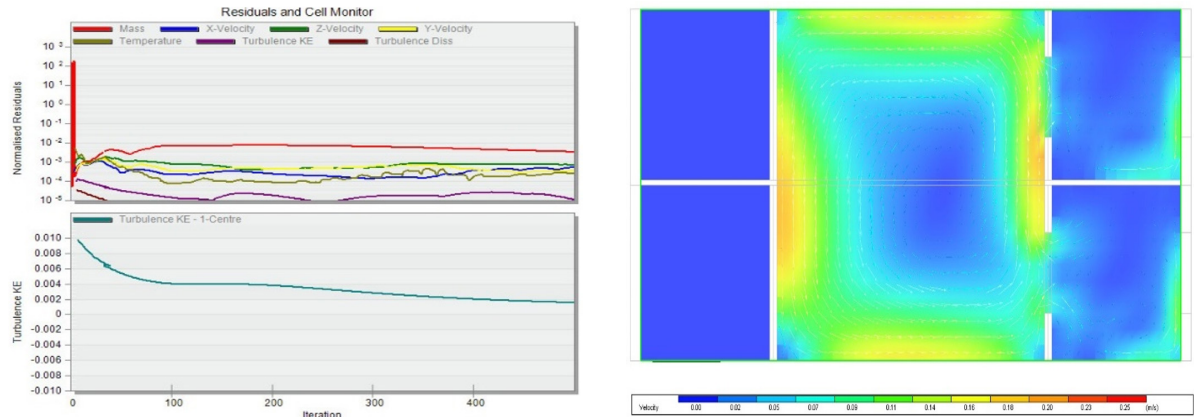


Figure 11: Air velocity in the yard, ground floor and first floor in the fourth scenario

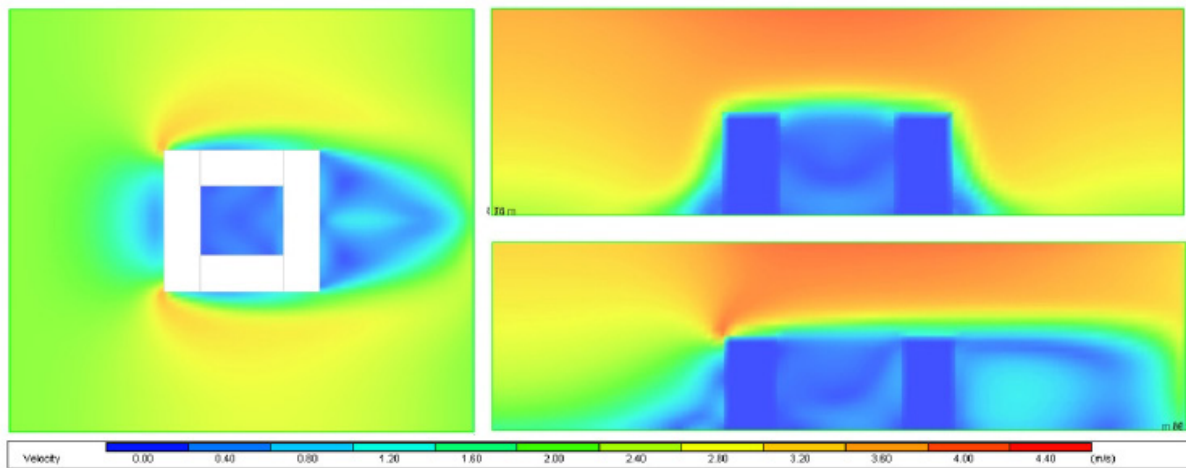


Figure 12: Air velocity in the yard and the space around the building in the fourth scenario

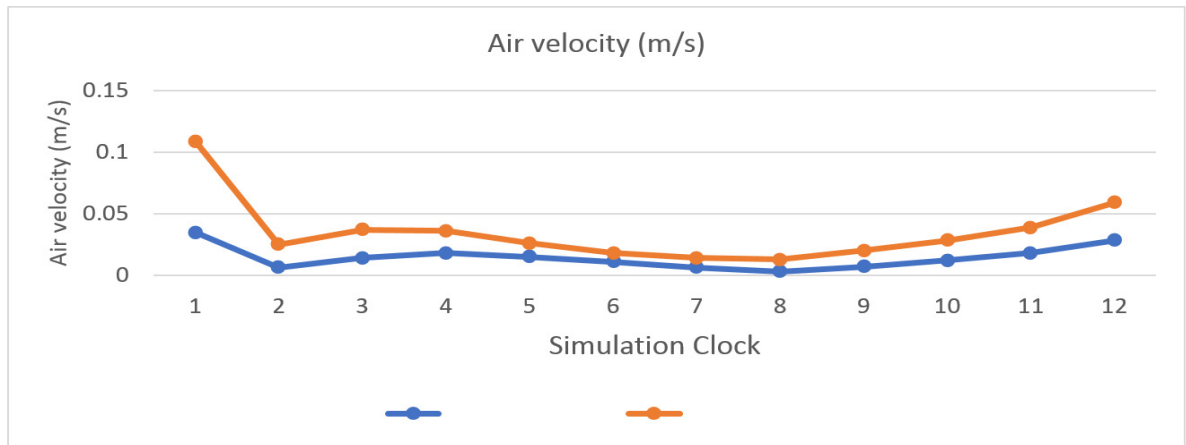


Figure 13: Air velocity between two windows in a room on the ground floor and the fourth floor

Scenario 5

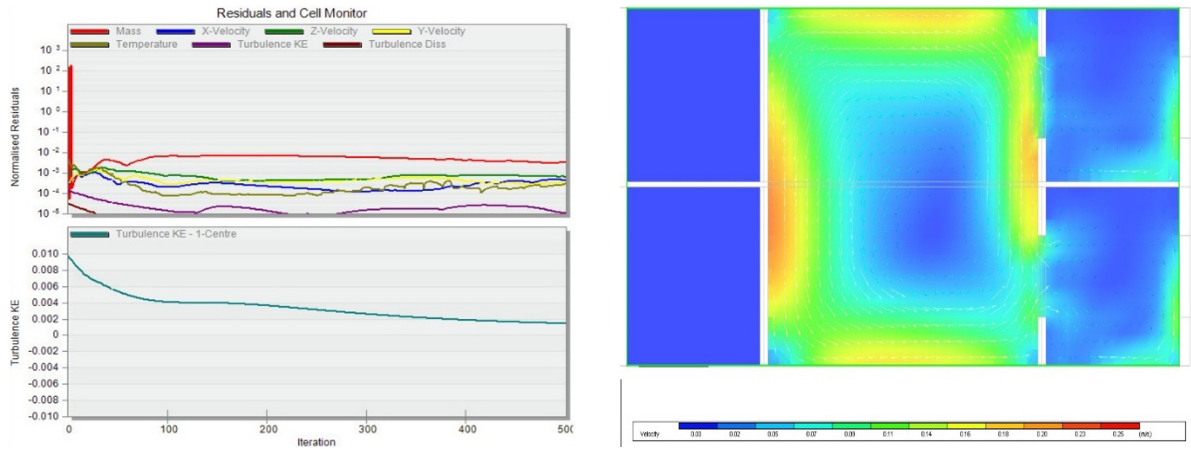


Figure 14: Air velocity in the courtyard, ground floor and first floor in the fifth scenario.

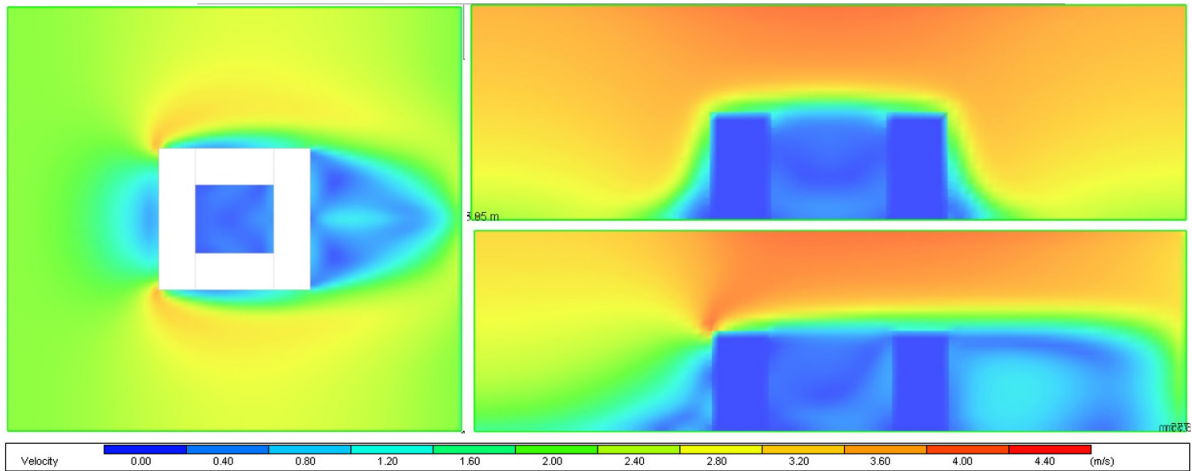


Figure 15: Air velocity in the yard and the space around the building in the fifth scenario

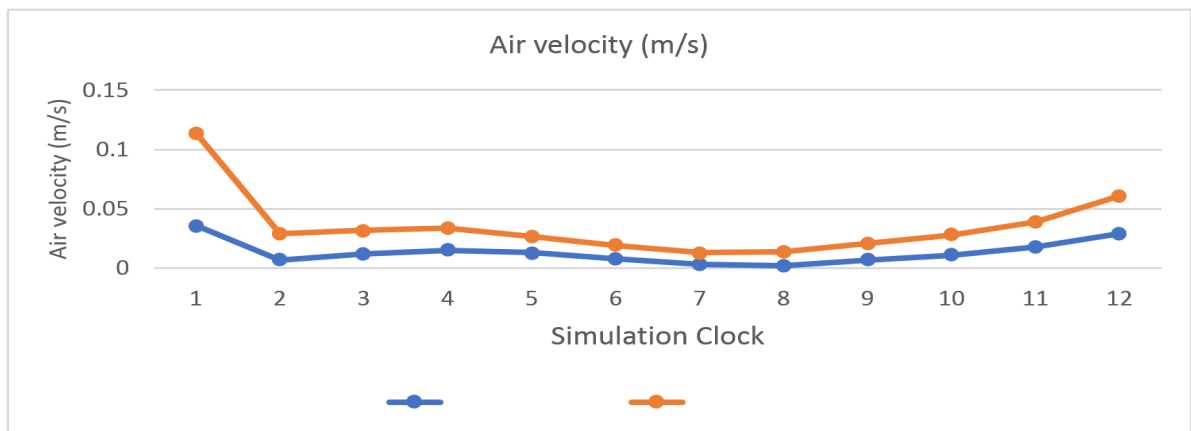


Figure 16: Air velocity between two windows in a room on the ground floor and the fifth floor

Scenario 6

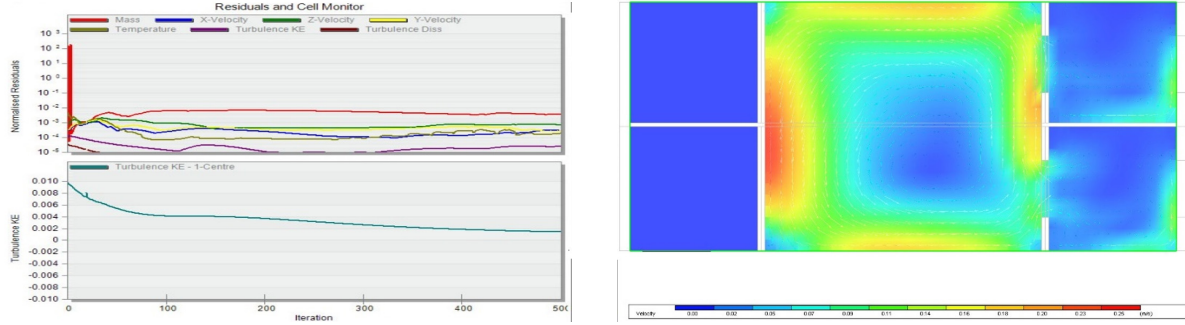


Figure 17: Air velocity in the courtyard, ground floor and first floor in the sixth scenario

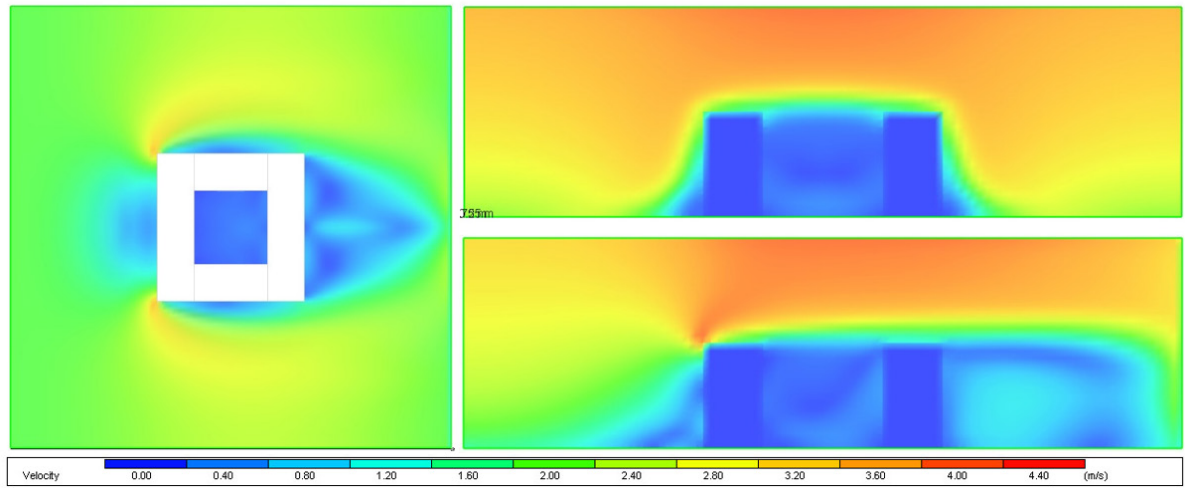


Figure 18: Air velocity in the yard and the space around the building in the sixth scenario

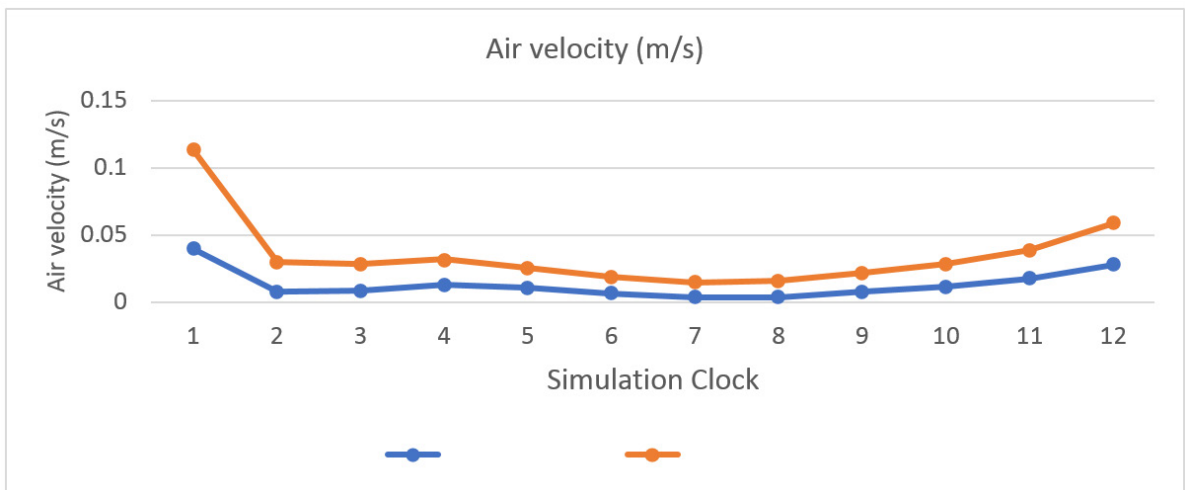


Figure 19: Air velocity between two windows in a room on the ground floor and the sixth floor

Scenario 7

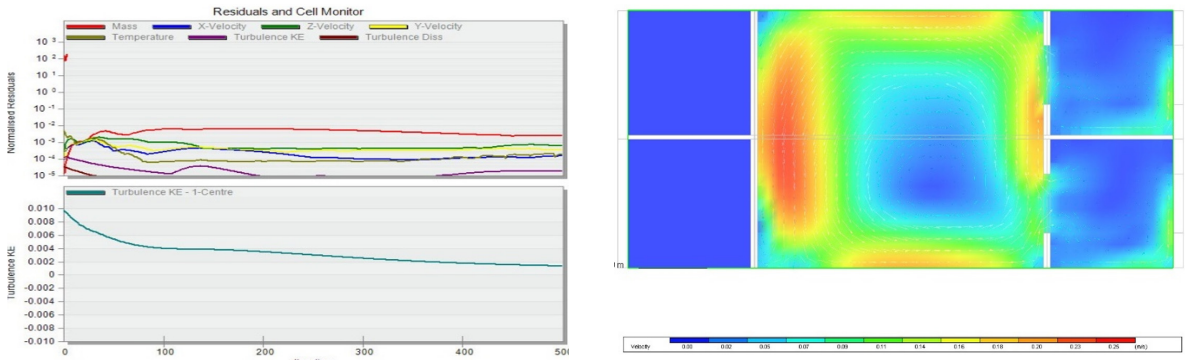


Figure 20: Air velocity in the courtyard, ground floor and first floor in the seventh scenario

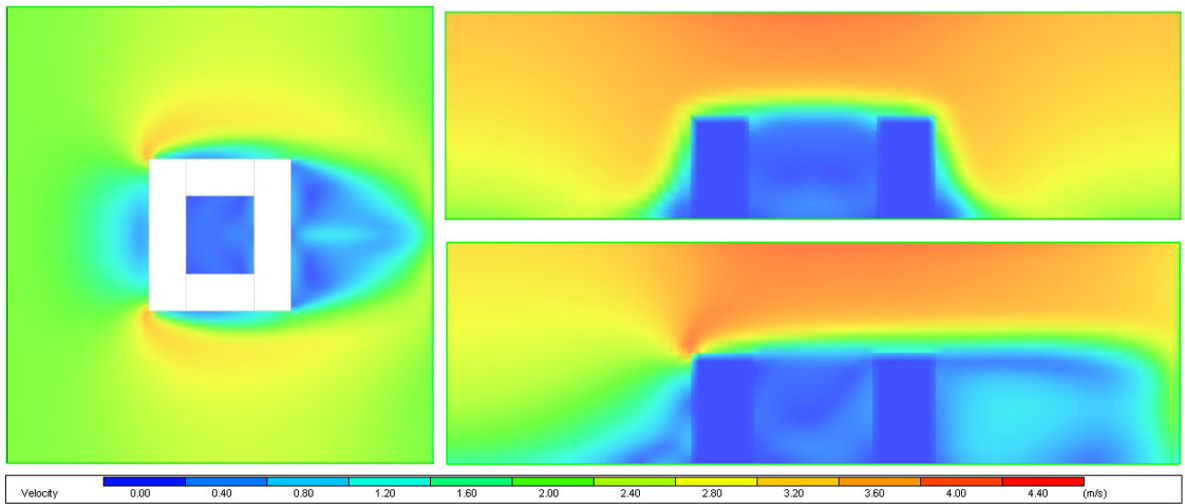


Figure 21: Air velocity in the yard and the space around the building in the seventh scenario

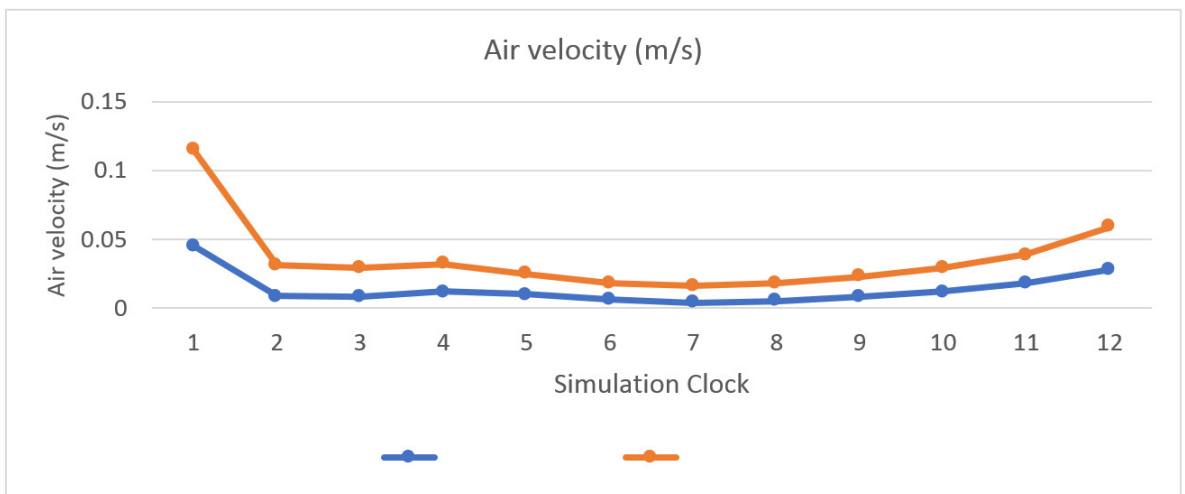


Figure 22: Air velocity between two windows in a room on the ground floor and the seventh floor

Scenario 8

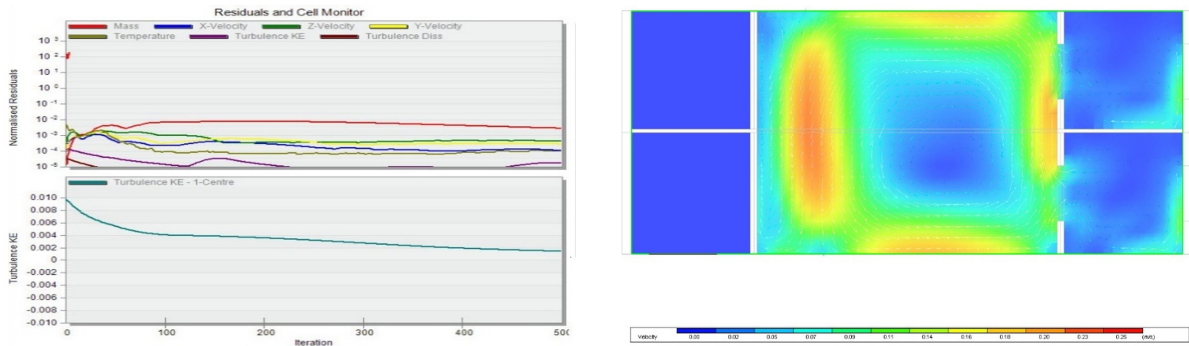


Figure 23: Air velocity in the courtyard, ground floor, and first floor in the eighth scenario

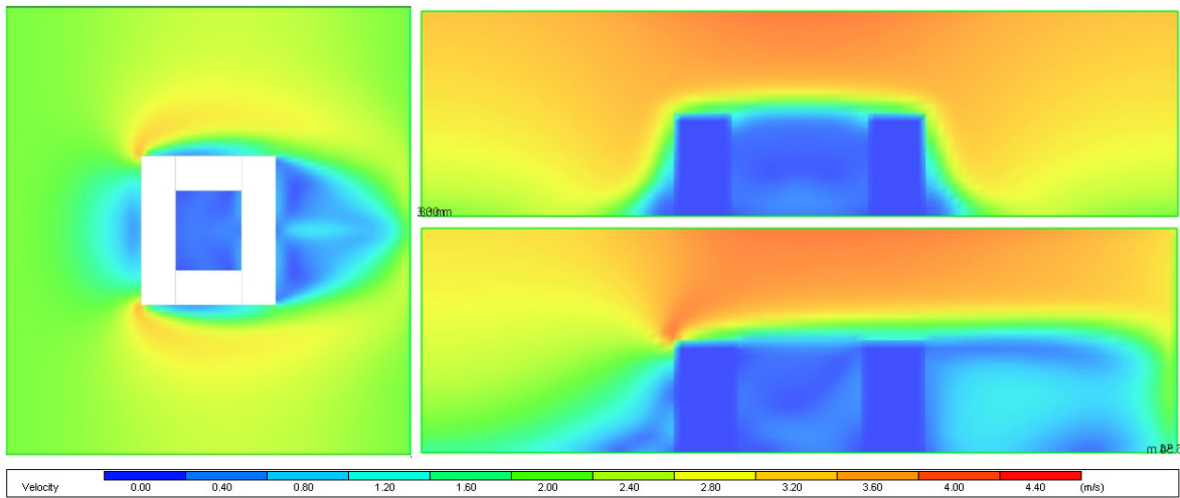


Figure 24: Air velocity in the yard and the space around the building in the eighth scenario

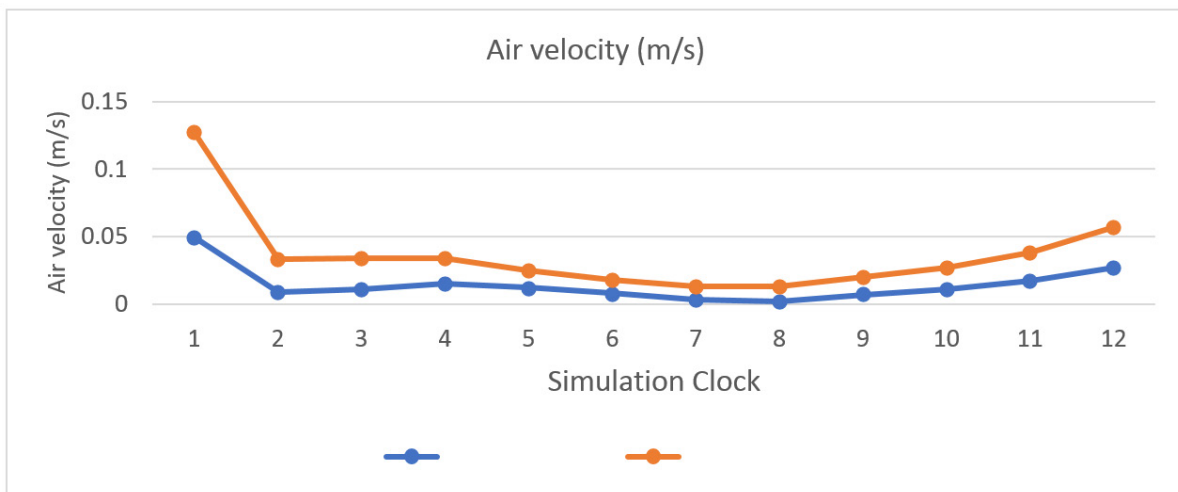


Figure 25: Air velocity between two windows in a room on the ground floor and the eighth floor

Scenario 9

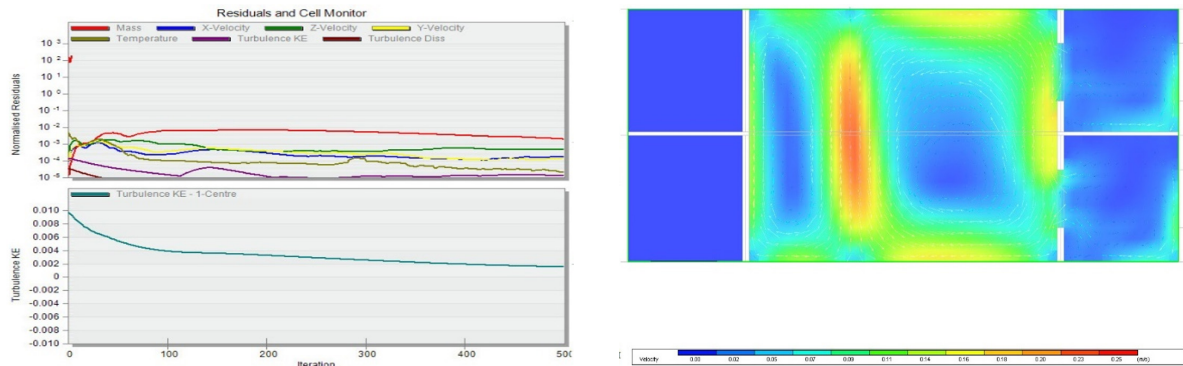


Figure 26: Air velocity in the courtyard, ground floor, and first floor in scenario 9.

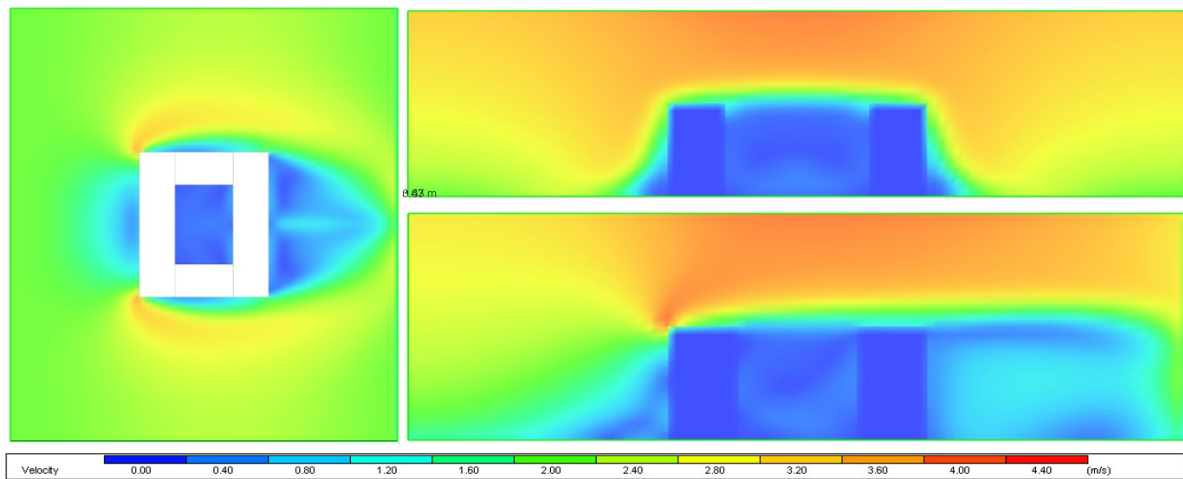


Figure 27: Air velocity in the yard and the space around the building in the ninth scenario

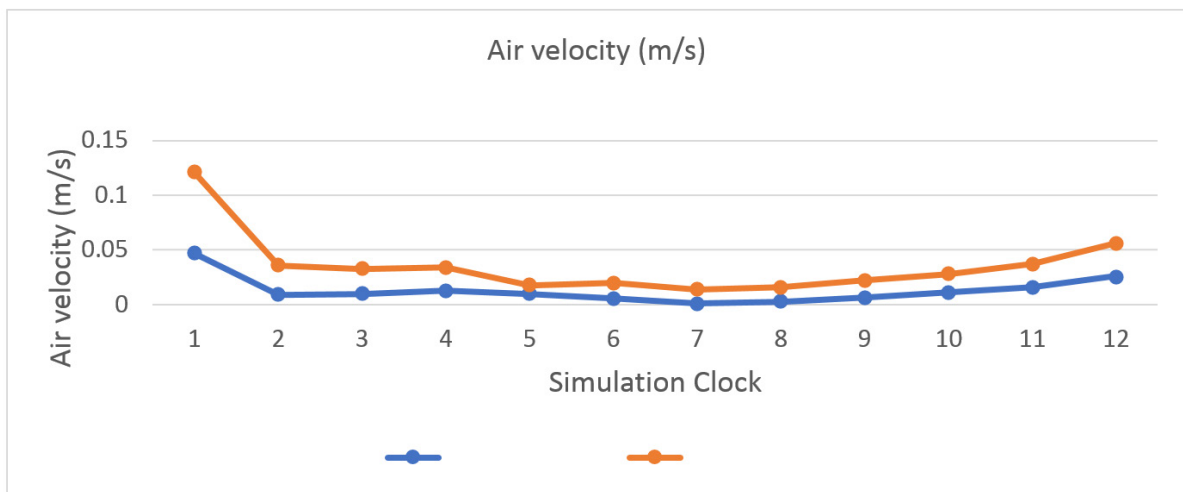


Figure 28: Air velocity between two windows in a room on the ground floor and the ninth floor

Scenario 10

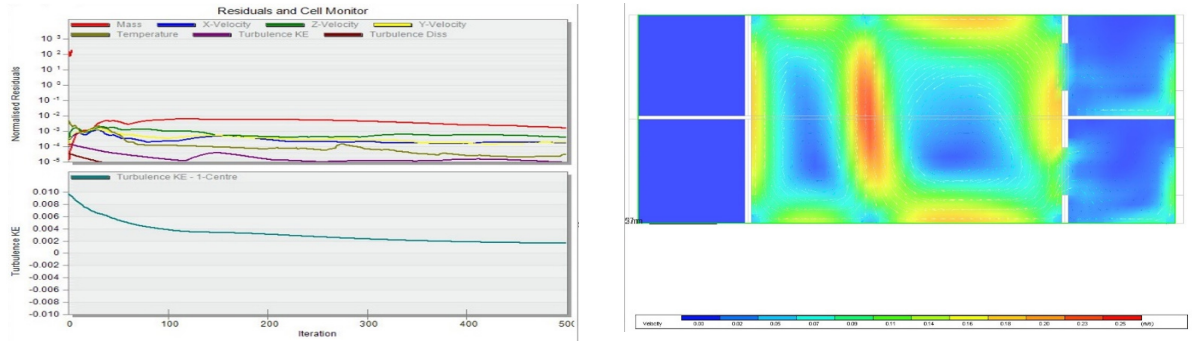


Figure 29: Air velocity in the courtyard, ground floor, and first floor in scenario 10

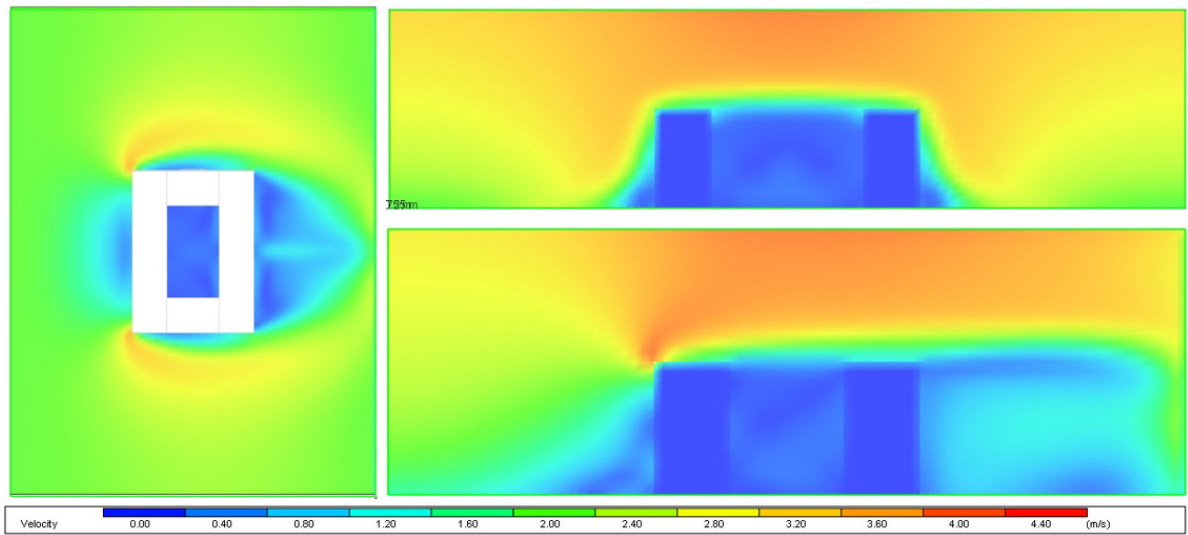


Figure 30: Air velocity in the yard and the space around the building in the tenth scenario



Figure 31: Air velocity between two windows in a room on the ground floor and the tenth floor

Scenario 11

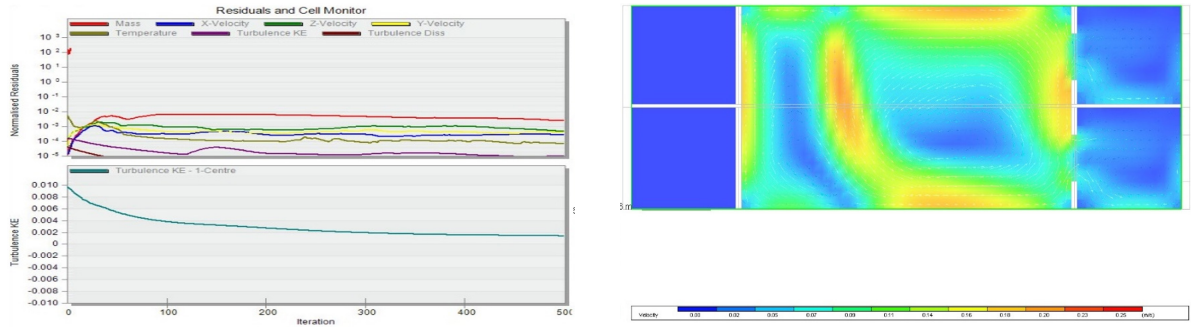


Figure 32: Air velocity in the courtyard, ground floor, and first floor in scenario 11.

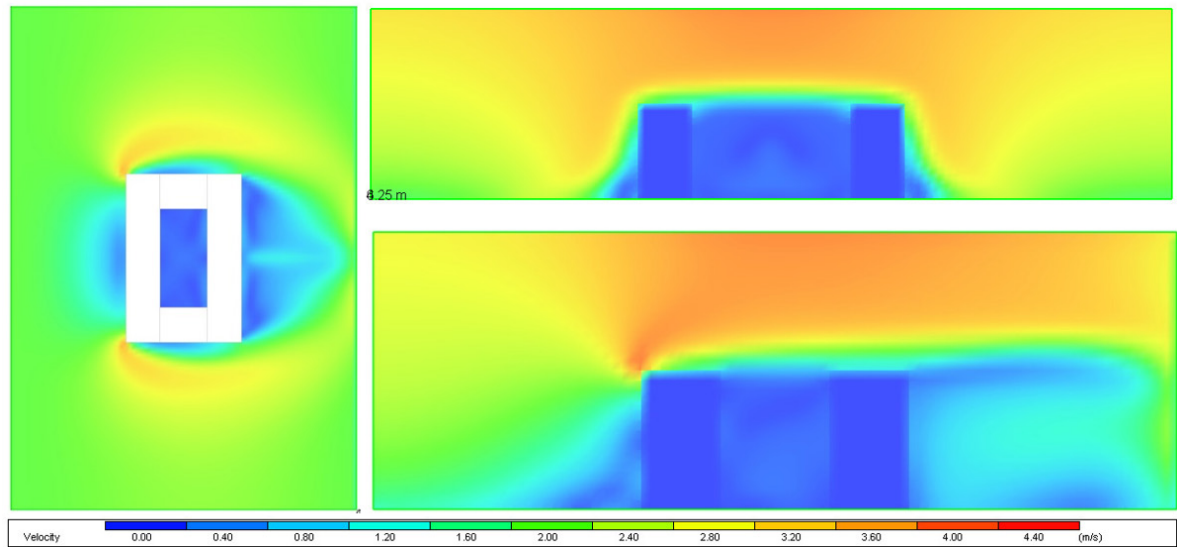


Figure 33: Air velocity in the yard and the space around the building in the eleventh scenario

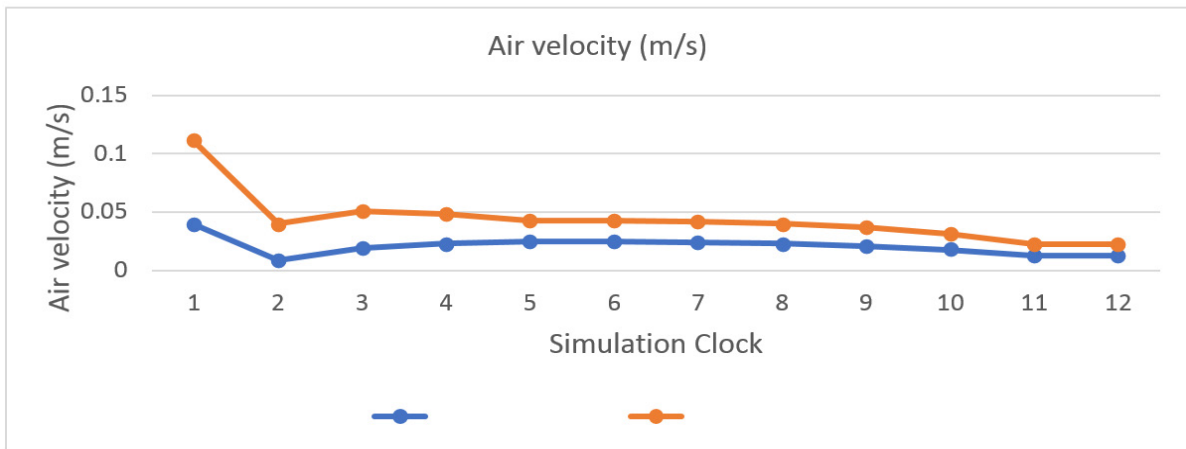


Figure 34: Air velocity between two windows in a room on the ground floor and the eleventh floor

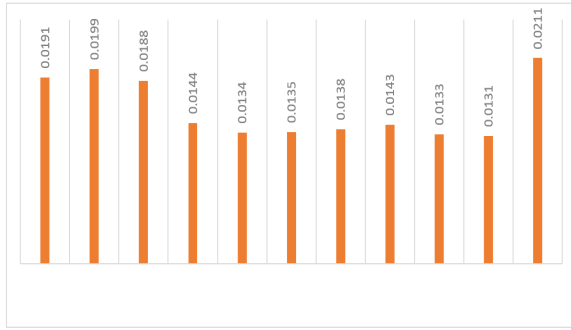


Figure 35: Average air velocity (m/s) of the first floor room in the scenarios

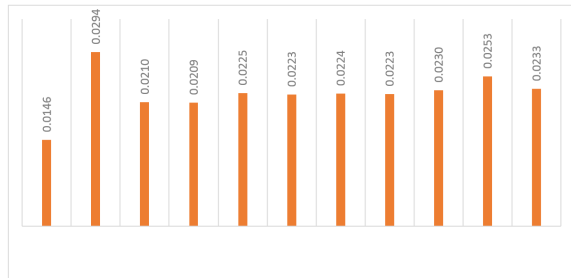


Figure 36: Average air velocity (m/s) of the first floor room in the scenarios

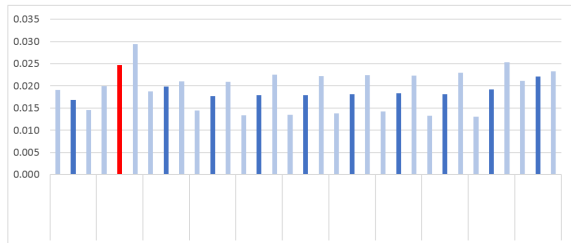


Figure 37: Average air velocity (m/s) of ground and first floor rooms in scenarios

## INTRODUCTION

The simulation results demonstrate that courtyard geometry plays a decisive role in regulating airflow patterns and ventilation performance in traditional residential buildings located in hot and humid climates. Across the eleven simulated scenarios, clear differences were observed in air velocity distribution within the courtyard and adjacent interior spaces, highlighting the sensitivity of natural ventilation performance to courtyard proportions and spatial configuration.

The analysis indicates that courtyard aspect ratio significantly affects the vertical and horizontal movement of airflow. Courtyards with low length-to-width ratios (below approximately 0.7) generally exhibited limited air penetration into interior spaces, particularly on the first floor. In these configurations, airflow tended to dissipate within the courtyard space, resulting in weaker pressure differentials between opposing openings. As a consequence, ventilation performance on upper floors was often lower than expected, unless façade openings were deliberately aligned with the prevailing wind direction to guide airflow inward.

In contrast, medium to high aspect ratios demonstrated a noticeably improved ventilation performance, especially on the first floor. Courtyard configurations with length-to-width ratios ranging from approximately 1.0 to 2.1 facilitated stronger airflow channels by enhancing pressure gradients and promoting more stable wind paths through interior spaces. These scenarios consistently showed higher average air velocity values in rooms connected to the courtyard, indicating more effective natural ventilation. The improvement was particularly evident when courtyard elongation was aligned with the prevailing wind direction, allowing external airflow to be drawn into the courtyard and distributed vertically and horizontally through the building. A comparative analysis between ground and first-floor spaces revealed that ventilation performance is not solely dependent on courtyard geometry but is also strongly influenced by the availability and alignment of airflow paths. While ground-floor spaces generally benefited from direct interaction with the courtyard, first-floor rooms showed greater sensitivity to changes in courtyard proportions. In scenarios with optimized aspect ratios and appropriately positioned openings, first-floor ventilation performance exceeded that of the ground floor, despite the uniform building height applied across all simulations. This finding underscores the importance of coordinated design between

courtyard geometry and opening configuration to achieve balanced ventilation performance across multiple building levels. The results further indicate that increasing the courtyard length-to-width ratio contributes to improved shading conditions and reduced solar heat gain on courtyard-facing façades. This reduction in heat load indirectly enhances ventilation efficiency by lowering air temperature within the courtyard microclimate, thereby supporting more effective airflow movement. The combined effect of geometric proportion, shading potential, and airflow direction highlights the interdependent nature of passive design strategies in hot and humid environments. Overall, the findings confirm that courtyard-based ventilation performance cannot be optimized through geometric modification alone. Rather, effective natural ventilation emerges from the integrated interaction between courtyard proportions, building height, façade openings, and prevailing wind direction. By systematically comparing multiple courtyard configurations under consistent climatic conditions, this study demonstrates that medium to high courtyard aspect ratios provide a more stable and efficient ventilation environment, particularly for upper-floor spaces. These results offer quantitative support for the adaptive use of traditional courtyard principles in contemporary residential design, emphasizing the value of proportion-driven passive strategies for improving indoor air quality and reducing dependence on mechanical cooling systems in hot and humid climates.

From a design perspective, the results emphasize that effective natural ventilation in courtyard-based residential buildings emerges from the interaction between courtyard geometry, building height, opening configuration, and wind orientation. The optimized courtyard proportions identified in this study provide practical guidelines for architects seeking to adapt traditional design principles to contemporary residential contexts. Future research may extend this framework by incorporating thermal

comfort indices, seasonal variability, and occupant behavior to further refine courtyard-based ventilation strategies.

## REFERENCES

- Bai, C.; Zhan, J.; Wang, H.; Yang, Z.; Liu, H.; Liu, W.; Wang, C.; Chu, X.; Teng, Y. (2023) Heating choices and residential willingness to pay for clean heating: Evidence from a household survey in rural China. *Energy Policy*, 178, 113617. <https://doi.org/10.1016/j.enpol.2023.113617>
- Figueroa-Lopez, A.; Arias, A.; Oregi, X.; Rodriguez, I. (2021) Evaluation of passive strategies, natural ventilation and shading systems, to reduce overheating risk in a passive house tower in the north of Spain during the warm season. *J. Build. Eng.*, 43, 102607. <https://doi.org/10.1016/j.job.2021.102607>
- Fine, J.P.; Zhang, S.; Li, Y.; Touchie, M.F. (2022) Analysis of solar chimney ventilation systems in high-rise residential buildings using parallel flow networks. *Build. Environ.*, 218, 109096 <https://doi.org/10.1016/j.buildenv.2022.109096>
- Gao, Y.; He, F.; Meng, X.; Wang, Z.; Zhang, M.; Yu, H.; Gao, W. (2020) Thermal behavior analysis of hollow bricks filled with phase-change material (PCM). *J. Build. Eng.*, 31, 101447. <https://doi.org/10.1016/j.job.2020.101447>
- Ghobadian, V. (2009). *Sustainable Traditional Buildings of Iran, A Climatic Analysis*, Islamic Azad University, Universal Publisher, Beirut.
- Hou, J.; Zhang, T.; Liu, Z.; Hou, C.; Fukuda, H. (2022) A study on influencing factors of optimum insulation thickness of exterior walls for rural traditional dwellings in northeast of Sichuan hills, China. *Case Stud. Constr. Mater.*, 16, e01033. <https://doi.org/10.1016/j.cscm.2022.e01033>
- Hussein, M.; Maghrabie Abdelkareem, M.A.; Elsaid, K.; Sayed, E.T.; Radwan, A.; Rezk, H.; Wilberforce, T.; Abo-Khalil, A.G.; Olabi, A.G. (2022) A review of solar chimney for natural ventilation of residential and non-residential buildings. *Sustain. Energy Technol. Assess.*, 52 Pt B, 102082.
- Karyono, K.; Abdullah, B.M.; Cotgrave, A.J.; Bras, A. (2020) The adaptive thermal comfort review from the 1920s, the present, and the future. *Dev. Built Environ.*, 4, 100032. <https://doi.org/10.1016/j.dibe.2020.100032>

- Lim SS, Vos T, Flaxman AD, et al. (2012) A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet.*;380:2224-2260. doi:10.1016/S0140-6736(12)61766-8.
- Lin, Y.; Zhao, L.; Yang,W.; Hao, X.; Li, C.-Q. (2021) A review on research and development of passive building in China. *J. Build. Eng.*, 42, 102509. <https://doi.org/10.1016/j.jobe.2021.102509>
- Logue J.M, Price P.N, Sherman M.H, (2012) Singer BC. A method to estimate the chronic health impact of air pollutants in U.S. residences. *Environ Health Perspect.*;120:216-222.
- Park, S.; Lee, S.; Yeo, M. S.; Rim, D. (2023) Performance of a heat recovery ventilation system for controlling human exposure to airborne particles in a residential building. *Build. Environ.*, 239, 110412. <https://doi.org/10.1016/j.buildenv.2023.110412>
- Piselli, C.; Prabhakar, M.; De Gracia, A.; Saffari, M.; Pisello, A.L.; Cabeza, L.F. (2020) Optimal control of natural ventilation as passive cooling strategy for improving the energy performance of building envelope with PCM integration. *Renew. Energy.*, 162, 171–181. <https://doi.org/10.1016/j.renene.2020.07.043>
- Shen, H.-Y.; Zhang, Y.; Lu, X.-Y.; Chen, L.-B.; Zhu, N.-Z.; Xiao, H.; Yang, G.; Huang, C.; Dai, X.; Ye, J.; et al. (2025) How indoor decoration materials contribute to phthalates pollution: Uncovering occurrences, sources, and their implications for environmental burdens in households. *J. Hazard. Mater.*, 490, 137719. <https://doi.org/10.1016/j.jhazmat.2025.137719>
- Wen, Y.; Lau, S.-K.; Leng, J.; Zhou, K.; Cao, S. J. (2023) Passive ventilation for sustainable underground environments from traditional underground buildings and modern multiscale spaces. *Tunn. Undergr. Space Technol.*, 134, 105002. <https://doi.org/10.1016/j.tust.2023.105002>
- Zoure, A.N.; Genovese, P.V. (2023) Implementing natural ventilation and daylighting strategies for thermal comfort and energy efficiency in office buildings in Burkina Faso. *Energy Rep.*, 9, 3319–3342. <https://doi.org/10.1016/j.egy.2023.02.017>
- Zune, M.; Tubelo, R.; Rodrigues, L.; Gillott, M. (2021) Improving building thermal performance through an integration of Passivhaus envelope and shading in a tropical climate. *Energy Build.*, 253, 111521. <https://doi.org/10.1016/j.enbuild.2021.111521>

COPYRIGHTS

©2023 The author(s). This is an open access article distributed under the terms of the Creative Commons Attribution (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, as long as the original authors and source are cited. No permission is required from the authors or the publishers.



HOW TO CITE THIS ARTICLE

Abdoli,S. S. , Shahabzadeh,M. and Eskandari,H. (2025). Improvement of Indoor Air Quality in Hot and Humid Climate in Central Yard Houses. (e730643). *International Journal of Urban Management and Energy Sustainability.* (), e730643

DOI: [10.22034/ijumes.2025.2073164.1339](https://doi.org/10.22034/ijumes.2025.2073164.1339)

