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Original Research Article

The Effect of Yard Proportions and Length on Indoor Ventilation Efficiency in Central Courtyard Houses in Hot and Humid Climates*

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Abstract

Problem statement: The use of the central courtyard in different regions of Iran had become a tradition in the past architecture of Iran. As ventilation is of great importance in a hot and humid climate, the structure of the central courtyard in the building can play an effective role in this matter. However, no research has been done on the central courtyard's proportions and its role in improving ventilation in the surrounding spaces needs more investigation.

Research objective: This research attempts to investigate the role of proportions and elongation of the central courtyard in creating ventilation in the surrounding spaces in hot and humid climates.

Research method: For this purpose, one of the most important ventilation indicators, including wind speed, was measured in a field (experimentally) in one of the traditional houses with a central courtyard pattern. These results are used as a base index for the analysis of other samples. In the next step, 10 samples were extracted based on the proportions and length of the yard, all of which were simulated under the same climatic conditions in the computational fluid dynamics software environment, and finally, the results were presented in the form of different outputs such as wind speed, air age, air flow rate and finally ventilation efficiency was measured. The independent variable in this research is the horizontal proportions of the central courtyard and the dependent variable is the efficiency of ventilation in the space available in the ax of the central courtyard.

Conclusion: The results of the research showed that in the central courtyard buildings, with the increase of the courtyard extension along the external airflow of the building, the ventilation efficiency increases significantly.

Keywords: *Proportions of the central courtyard, Ventilation, Hot and humid climate, Spaces around the courtyard.*

Introduction

Traditional vernacular architecture, including the prevalent use of central courtyards, has historically offered solutions for creating a sustainable relationship between climatic factors and built environments (Abro, 1994; Fathy et al., 1996). In Iran, the design of buildings with central courtyards has been a common practice, particularly in regions with hot and humid climates such as Bushehr (Zamani et al., 2018). In such a model, in addition to cultural contexts, climatic issues have

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also been considered (Zhu et al., 2023); In such a way that the use of the central courtyard creates a micro-climate in the housing scale and protects the residents from dealing with the harsh and generally exhausting climate of the outside environment (Nosek et al., 2022; Taleghani et al., 2014).

The construction of the building in the style of the central courtyard can be seen in different parts of the country, from the central parts and to some extent in the southern regions of Iran. Bushehr is one of the cities where the construction of buildings in the style of the central courtyard can be seen to a large extent in its traditional architecture. Considering the hot and humid climate of this region, ventilation is one of the most important challenges facing this architecture. However, the question may arise as to how ventilation is possible in a building with a central courtyard pattern in the hot and humid climate of Bushehr. Undoubtedly, various architectural factors affect this issue, among which we can mention the orientation of the building, the mass-to-space ratio, the height dimensions of the space, and the relationship between the building and its surrounding context (Soflaei et al., 2016). However, one of these factors is the issue of the proportions of the central courtyard and its type of elongation in connection with the prevailing urban wind. Based on this, the present research analyzes the role of proportions and length of the yard on ventilation in the interior of houses with a central courtyard in a hot and humid climate. Based on this, first, with the climatic analysis of one of the traditional houses built with a central courtyard pattern in Bushehr city, natural ventilation indicators including wind speed will be measured. In the next step, by designing different central courtyard buildings with different proportions and elongations as a case study, an attempt was made to analyze the ventilation situation in the interior spaces overlooking the courtyard using CFD simulation. With this explanation, the main question in the current research can be posed as follows: What effects do the proportions of the courtyard in a building with a central courtyard pattern have on the ventilation flow in the courtyard and the interior space (overlooking the courtyard)? It should be noted that in this research, the ratio of the length to the width of the yard is proportional.

Research Background

Due to the significance of the central courtyard in architecture, numerous studies have been conducted, examining the central courtyard from various perspectives, including cultural, functional, and climatic aspects (Zhu et al., 2023). Regarding the climatic role of this element, multiple research projects have specifically investigated issues such as shading, energy consumption, daylight, and ventilation (Zamani et al., 2018). According to the purpose of the present research regarding the role of the proportions of the central courtyard in the creation of ventilation in the space, in this section, only the research in which the issue of natural ventilation in the patterns of the central courtyard is investigated. The summary of this research is presented in Table 1.

As can be seen from Table 1, the issue of natural ventilation has been investigated in various researches, which have generally analyzed and investigated this issue using the CFD method. But what is significant is that in none of the cases, the dimensions and proportions of the central courtyard have been investigated. The only research that has addressed this issue to some extent is the one carried out by (Soflaei et al., 2016), in which the research focused only on the geometry and orientation of the courtyard and attempted to address the issue using a descriptive and analytical approach; This is despite of the role of the dimensions and proportions of the central courtyard in the natural ventilation of the spaces around the courtyard has not been presented in any research so far with a numerical method.

Research Method

As mentioned before, the main goal of this research is to investigate the effect of the proportions of the courtyard in a building with a central courtyard pattern in the hot and humid climate of Bushehr on the ventilation efficiency in the exterior and interior spaces of the building. For this purpose, the current research consists of two steps as follows.

- **First step: software validation**

This step is defined as the experimental part of the research (Figs. 1 & 2). For this purpose, Golshan house, a traditional house with a central courtyard pattern in Bushehr city was selected as a case study by referring to it in person during one week in July 2023, to collect data related to ventilation,

Table 1. Research conducted in connection with the issue of natural ventilation in central courtyard buildings. Source: Authors.

Source	Title	The purpose of the article	Analysis method	The output of the article
Mardani & Roasaei, 2021	The effect of the geometric pattern of the central courtyard on the airflow in Shushtar traditional houses.	Analysis of the role of the geometric characteristics of the yard on the airflow pattern inside the yard.	CFD simulation	As the shape of the yard becomes square-like in the climate of Shushtar, better ventilation takes place inside the yard.
Rahai, 2021	Investigating the physical changes of the central courtyards on the air flow pattern inside them in the Qajar era houses of Isfahan	Investigating the changes in the dimensions of the central courtyard during the Qajar period and its effect on the air flow pattern inside the courtyard	CFD simulation	With the increase in the dimensions of the yard, the air speed inside the yard has decreased and the air currents have formed in the form of eddies in the disturbed parts of the yard.
Nikghadam, 2015	Extraction of climatic patterns of functional spaces in native houses of Bandar Bushehr by applying database theory	Extraction and introduction patterns of functional spaces in the houses of Bandar Bushehr by applying the theory of database and matching the characteristics of these spaces with the climatic characteristics of Bushehr.	Documentary studies, field observations	In the pattern of the central courtyard in the traditional houses of Bushehr city, open and semi-open spaces are located between and in front of the closed spaces, and the extension of the closed spaces is in the direction of the courtyard. Therefore, at the same time as the overall density of the volume, the biological closed spaces function widely in terms of natural ventilation.
Nikghadam, 2016	The effect of wind and sun in adjusting the thermal conditions of Bushehr houses, case example: Golshan house	Analysis of the effectiveness of airflow and radiation conditions in creating comfort conditions in a central courtyard house model in Bushehr city	Simulation using Design Builder software	The use of the central courtyard pattern in Bushehr houses has a great role in adjusting the thermal conditions during the hot days of the year.
Shaeri et al., 2018	Investigation of temperature, relative humidity, and wind speed in traditional residential buildings of Bushehr in the summer season (case examples of Golshan Mansion and Dehdashti Mansion).	Investigation of the thermal behavior in Golshan and Dehdashti mansions.	Field observations and experimental studies	The thermal conditions of the indoor environment of buildings are more balanced and favorable than the hot and humid climate outside.
Khaksefidi et al., 2020	Optimal design of the central courtyard in residential buildings against the 120-day wind of Zabul based on CFD.	Investigation of the orientation and degree of enclosure of the central courtyard to reduce the wind speed.	CFD simulation	Buildings that have a concave shape against the direction of the wind prevent entry into the yard more than other types.
Soflaei et al., 2016	Analysis of building dimensions and orientation in the formation of microclimate in traditional Iranian buildings.	Investigation of the microclimate situation in all kinds of central courtyard buildings in Iran according to the dimensions, proportions, and orientation of the building.	Descriptive analysis based on field observations	The central courtyard in the building creates a micro-climate, which has an important effect on the thermal comfort of the courtyard space.
Sharples & Bensalem, 2001	Airflow analysis in buildings with central courtyards and atrium.	Comparison of flow rate and speed of airflow in buildings with atrium and buildings with central courtyard.	Wind tunnel – CFD simulation	The airflow rate in buildings with a central courtyard is significantly different from the air flow rate in buildings with atriums.
Moonen et al., 2011	Evaluation of the ventilation potential of courtyards and valleys of urban streets using RANS and LES.	Comparison of two RANS and LES solution methods in connection with the indoor air conditioning of a courtyard in a building with a central courtyard pattern.	CFD simulation	The use of the RANS model has provided higher accuracy in solving the ventilation equations in the central courtyard space.
Lopez-Cabeza et al., 2023	The effect of thermal inertia on natural ventilation and thermal comfort of users in central courtyard buildings.	Analyzing the role of the thermal inertia of the walls around the central courtyard on the formation of the ventilation of the courtyard.	CFD simulation	Increasing the thermal capacity of the walls around the courtyard in the patterns of the central courtyard, although during the day they slightly increase the temperature inside the courtyard, but during the night they increase the natural ventilation in this environment.

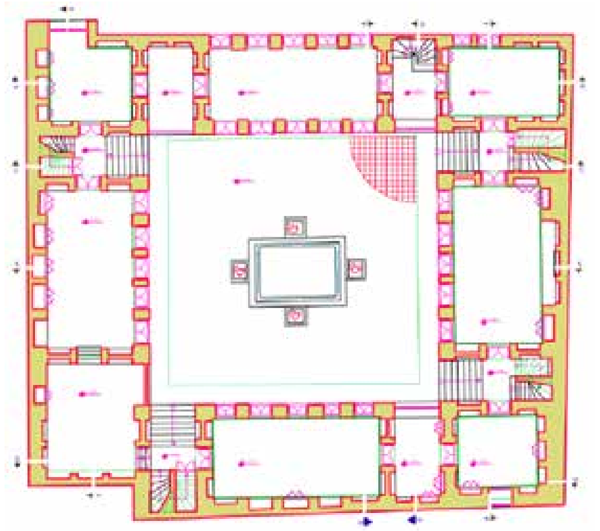
Fig. 1. Plan of Golshan house in Bushehr city. Source: Author's archive.


Fig. 2. Central courtyard in Golshan house. Source: Author's archive.

including The wind speed in the courtyard and its surrounding spaces (specifically, the 5-door room located on the north front of the building) was studied (Fig. 3). For this purpose, Testo 405i smart hotwire anemometer speedometer was used (Figs. 4). This device, which is equipped with a thermal wire sensor, has the possibility of picking up low air speeds, as well as the possibility of connecting to a computer and recording fluctuations related to airspeed. This device can measure air speed in the range of 0 to 30 meters per second with an accuracy of ± 1 and temperature measurement between - 20 to + 60 degrees Celsius with an accuracy of ±0. 5 degrees Celsius. References are made four times in the morning, noon, evening, and nighttime intervals and finally, the average speed of air passing through the desired room during one day is extracted. To use the data in the software validation section, the speedometer device was placed at a height of 170 cm from the ground and between two windows of the room with 0. 5 meter intervals and data was recorded.

As mentioned before, the CFD simulation method was used in this research to analyze case samples, and Autodesk CFD 2018 software was used in this connection. In the CFD method, software validation is an essential issue. Accordingly, the experimental data obtained from the first step were used to validate the software.

- **Analysis of samples in CFD**

After determining the characteristics of the case samples, the CFD method was used to analyze the flow pattern inside each sample. For this purpose, three-dimensional models were first made from case samples, and then each of them was placed in a wind tunnel with the dimensions of 5HWT and 10HWT upstream and downstream, 5HWT on the sides, and 5HWT in height. Considering the dimensions of 6. 5 × 14 × 14 meters for the reference building, the dimensions of the computational domain investigated in this research were 143. 5 × 78 × 38. 5 m3. Also, in defining the boundary conditions, a uniform flow pattern at the entrance of the domain at the rate of 3 m/s and zero static pressure at the end of the domain was used. In the construction of the mesh network in the computational domain, a hexahedral mesh was used, and the number of cells in the case samples of the research fluctuated from 1025412 to 1398125 (Fig. 5). In this research, the RANS model is used to solve the equations; Also, the k-ε turbulence model has been used in the simulation and analysis of the samples. Equations 1 to 3 are of wind speed (U), kinetic energy (K), and turbulence model (E) used in the software.

In Equations 1 to 3, y is the height of the wind measurement, UABL is the friction velocity, K is von Karmann's constant (0. 40 to 0.42) and C_M is a constant value of the k-μ model. The case samples in this research were simulated based on the weather conditions of Bushehr city. According to the

Eq. (1)
$$U(y) = \frac{u^{*}_{ABL}}{k} ln\left(\frac{y + y_0}{y_0}\right)$$

Eq. (2)
$$k(y) = \frac{u^{*2}_{ABL}}{\sqrt{C_\mu}}$$

Eq. (3)
$$\varepsilon(y) = \frac{u^{*3}_{ABL}}{k(y + y_0)}$$

Fig. 3. Field impression of airspeed in Golshan house. Source: Author's archive.

Fig. 4.Testo model 405i anemometer. Source: Author's archive.

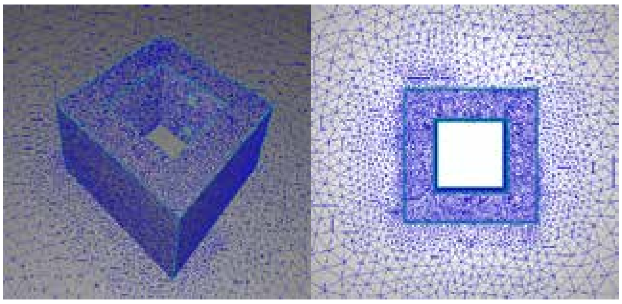

Fig. 5. Mesh pattern in the base sample with 1289124 cells. Source: Authors.

Table 2. Specifications related to research case samples. Source: Authors.

Sample number	The length of the yard	The width of the yard	Building height	Length-to-width ratio
Case_01	5.5	11.6	6.5	0.5
Case_02	6	10.7	6.5	0.6
Case_03	6.7	9.9	6.5	0.7
Case_04	7.7	9.3	6.5	0.8
Case_05	7.5	8.6	6.5	0.9
Case_06	8	8	6.5	1
Case_07	8.6	7.5	6.5	1.1
Case_08	9.3	7.1	6.5	1.3
Case_09	9.9	6.7	6.5	1.5
Case_10	10.7	6	6.5	1.8
Case_11	11.6	5.5	6.5	2.1

data of the Meteorological Organization, the average daily temperature in July in Bushehr city is 42 degrees Celsius and the average air speed in this month is 2. 1 meters per second (Shaeri et al., 2018). In all simulations, the wind angle is zero. degree is considered (θ = 0°).

Considering that the independent variable in this research is the longitudinal and transverse proportions of the central courtyard, therefore, 11 patterns according to Table 2 and Fig. 6 were determined as case examples of the research. According to the almost square plan of the Golshan house (as an experimental sample of the research), Case_ 06 with a square plan has been considered as a reference sample in this research. Other samples are formed based on the change in the ratio of length to width of the yard from 0. 5 to 2.1. In addition to presenting the numerical characteristics of the case samples in Table 2, in Fig. 6, the shape changes of the proportions of the yard in the case samples can be seen. In this regard, it is important to mention that in determining the

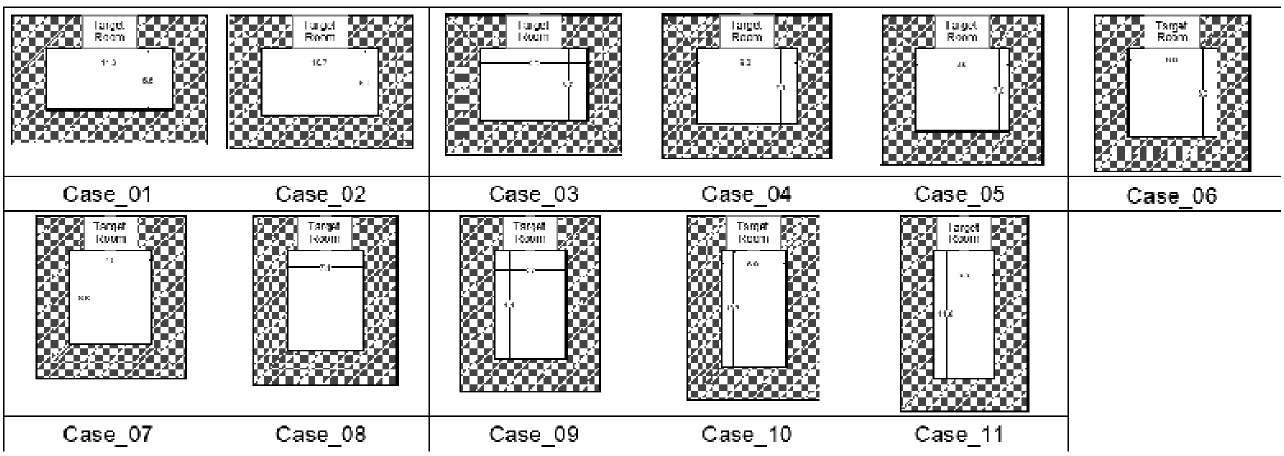

Fig. 6. Shape changes of yard proportions in research case samples Source: Authors.

case samples, the constant area of the yard in the samples was considered a determining principle. Accordingly, the length and width proportions of the yard in the samples were chosen in such a way that the area of the yard was constant in all the samples. Also, due to the constant length of the target room in the samples, the smallest possible factor in determining the dimensions of the yard was considered to be 5. 5 meters (equivalent to the length of the mentioned room). On the other hand, due to the fact that the wind direction is constant 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 in the state perpendicular to the prevailing wind.

Findings

As mentioned in the research method section, in the first step (Fig. 7) of the current research, software validation was done. Based on this, the experimental data collected from the Golshan house on June 16, 2023, related to the two spaces of the central courtyard and the five-door room located on the first floor of the north front of the house were compared with the data obtained from the simulation of the house in the CFD environment. In this comparison, the airflow speed variable was examined, the results of which can be seen in Figs. 8 & 9. The experimental findings and CFD data depicted in the aforementioned graphs exhibit a notable level of agreement across both spaces scrutinized in this study. This is evident from the fact that the error rates resulting from the comparison of numerical and experimental results for the courtyard and the fifth room are determined to be 7% and 9% respectively. These outcomes signify the precision of the simulation, consequently validating the software utilized in this study for analyzing the research case samples. Following the validation of the software's integrity, the study proceeds to analyze specific case examples. As the research primarily focuses on the interior ventilation quality of the house, the analysis encompasses two key variables: air speed and ventilation efficiency. These variables serve as indicators for assessing the quality of interior ventilation. Fig. 10 presents the quantitative air velocity values between the openings in the rooms on the first and ground floors across the case samples.

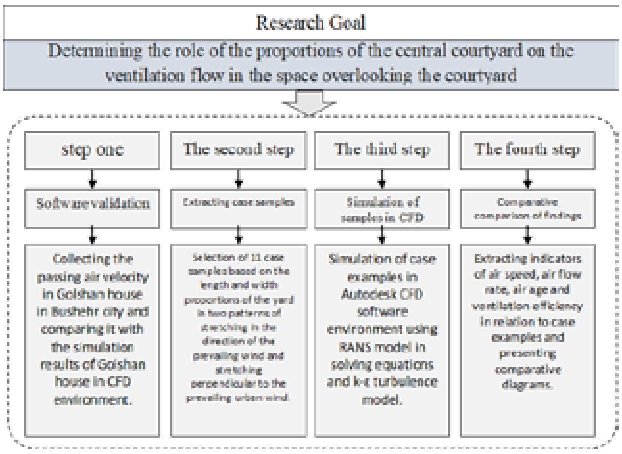

Fig. 7. Diagram of the research process. Source: Authors.

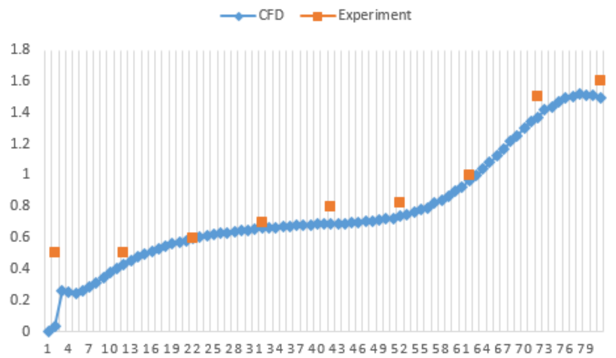

Fig. 8. Comparison of field survey results and CFD data in connection with the airspeed index in Golshan's yard. Source: Authors.

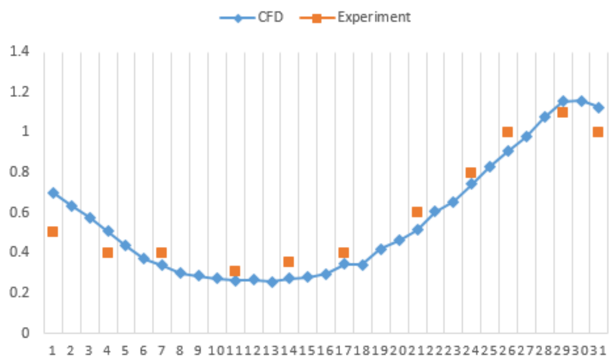

Fig. 9. Matching the results of the field survey and CFD data in connection with the air velocity index in the room located on the north front of the first floor of Golshan House. Source: Authors.

Additionally, Fig. 11 displays the transverse contours of airflow speed in the case samples. The data provided in Fig. 10 reveals that, across all case samples, the numerical air velocity values in the first-floor room surpass those obtained on the ground floor. Consequently, it can be inferred that within the central courtyard patterns, the average air speed in first-floor spaces exceeds that observed on the ground floor. This observation may elucidate the rationale behind the placement of guest spaces (such as the five-door room) on the first floor in traditional houses in Bushehr city, exemplified by the Golshan house.

Upon examining the numerical air speed values and airflow pattern illustrations in the rooms under investigation within the case samples, the average air speed values are compared based on the variations in the courtyard proportions. This comparison is depicted in Fig. 12. Moreover, Figs. 13 & 14 present the average air age and the airflow rate entering the room, respectively, within the case samples. To facilitate a more comprehensive analysis of the case examples concerning the fluctuations in the yard proportion patterns, the reference example is delineated in the form of

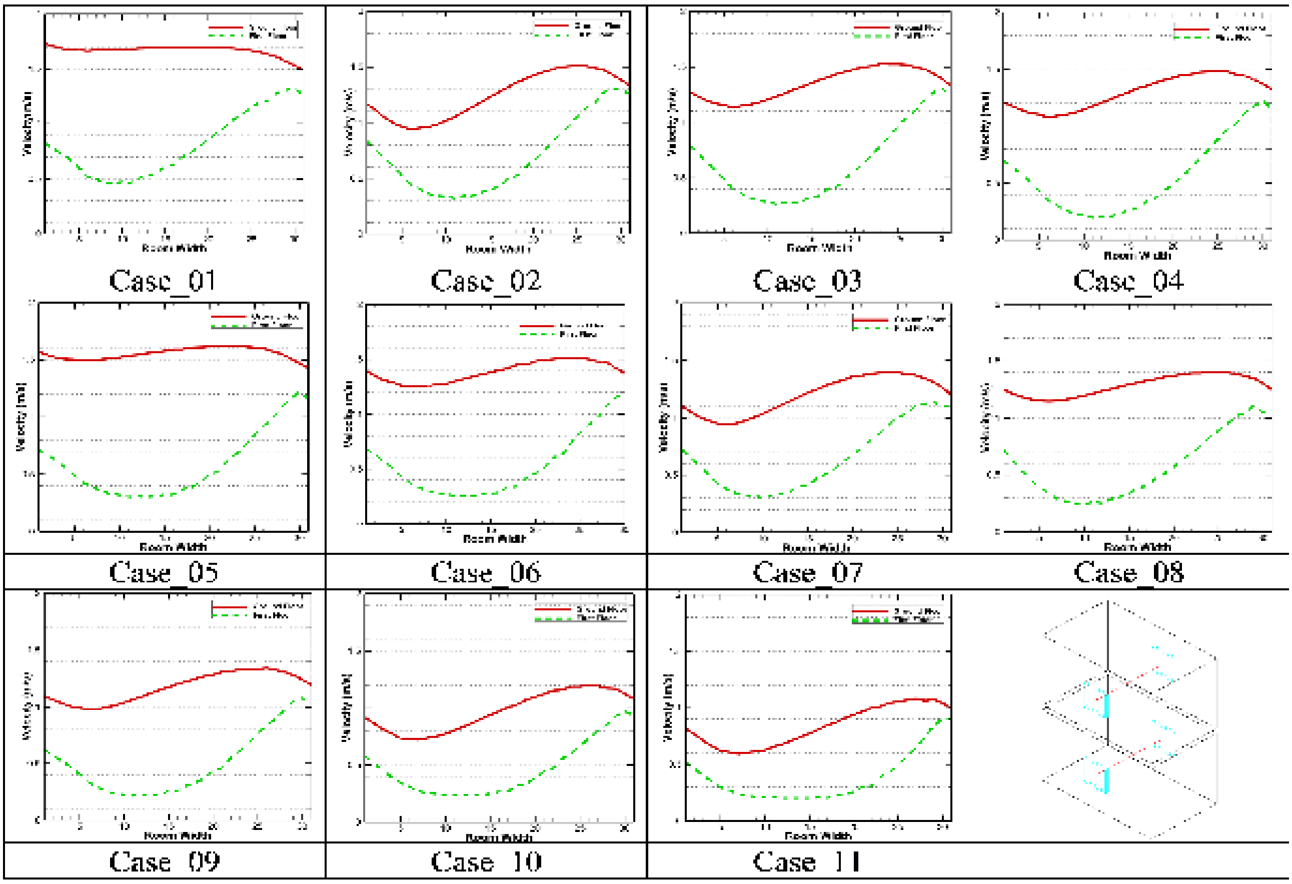

Fig. 10. Numerical values of between the openings in the ground floor and first floor rooms in case samples. Source: Authors.

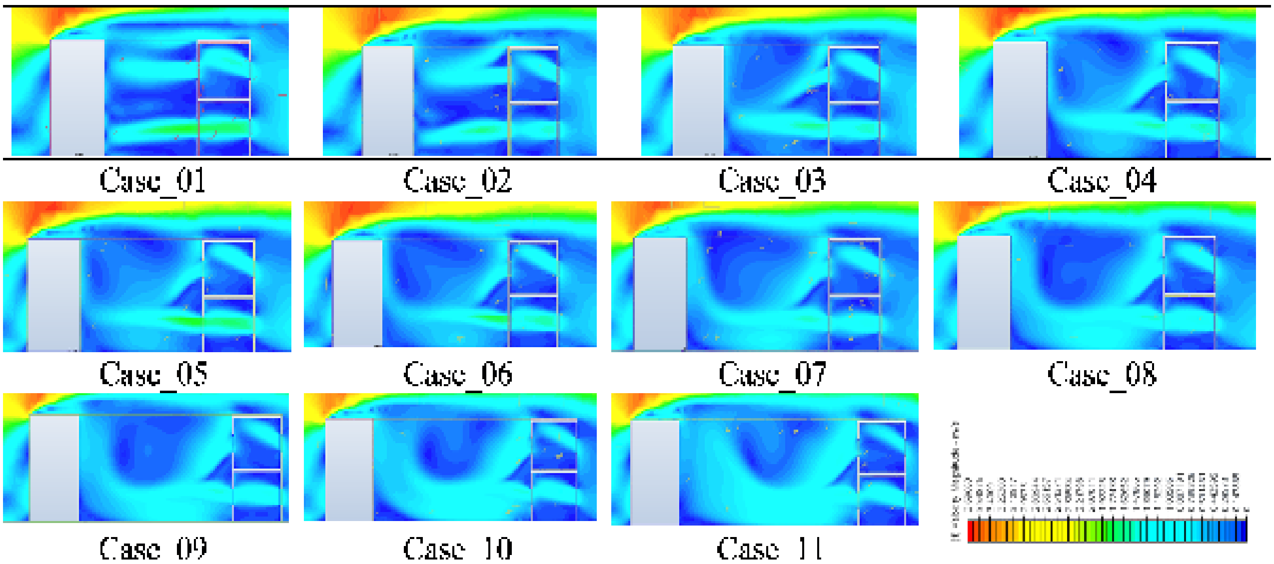

Fig. 11. Air velocity contour in the yard space and ground floor and first floor rooms located on the front facing the wind in case examples. Source: Authors.

case number 6. Consequently, from Case_ 01 to Case_11, the width of the yard has been diminished while the length of the yard has been increased. Specifically, the yard's elongation has transitioned from transverse to longitudinal along the direction of the prevailing wind from Case_ 01 to Case_11, with the wind direction remaining constant in the referenced examples. Upon observing Figs. 12 to 14, it is apparent that as the yard's length changes from width to length (from Case_ 01 to Case_11), both the average air speed within the room and the airflow entering the room have decreased (depicted in Figs. 9 & 13). Concurrently, no notable alterations have been detected concerning the air age within the room. Thus, it can be inferred that by elongating the yard along the direction of the prevailing wind, the volume of incoming airflow and the air speed within the room will diminish. Conversely, if the yard's length dominates in a direction perpendicular to the wind, the airflow entering the room and the internal air speed will increase. After the examination of variations in air speed, air age, and airflow entering the room in the case examples, this section addresses the analysis of ventilation efficiency in the examined rooms for each case example. As per existing literature, ventilation efficiency is determined by dividing the minimum possible time required to change the air in the room by the actual time taken to achieve air changes in the room (Heidari & Eskandari, 2022). Consequently, Equations 4 to 6 can be employed in this context:

In Equations 4 to 6, ε is the value of ventilation efficiency in each space, which is expressed as a percentage; T_m is the minimum possible time for changing the air in the space and T_r is the actual time of changing the air in the desired space; V is the volume of the desired space and Q is the flow rate of air entering it at the time of analysis.

According to the aforementioned relations, the ventilation efficiency for each of the rooms on the ground floor and the first floor of the case samples was analyzed, the results of which are shown in Fig. 15.

- By increasing the length of the yard along the outside airflow, the ventilation efficiency in the space has increased so that Case_ 10 and Case_ 11 have the highest ventilation efficiency, and Case_ 02 and Case_ 03 have the lowest ventilation efficiency compared to other cases.

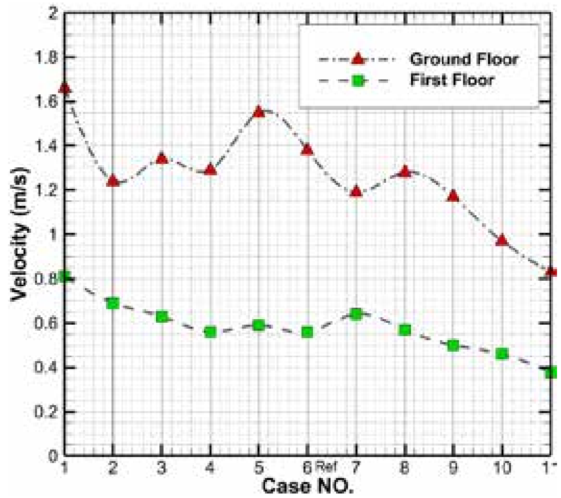

Fig. 12. Average air speed changes in the ground floor and first floor rooms in case samples. Source: Authors.

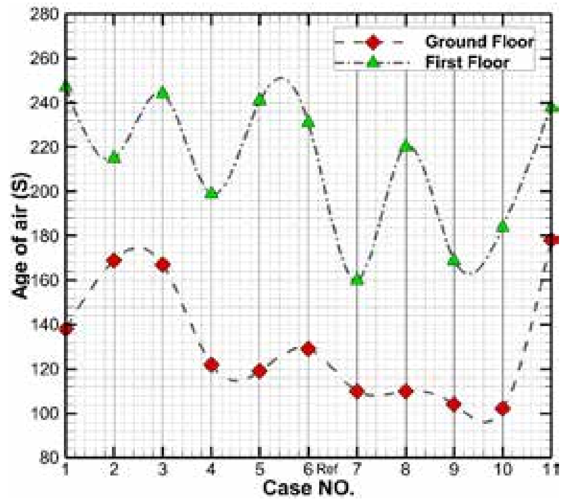

Fig. 13. Changes in the average age of the air in the ground floor and first floor rooms in case samples. Source: Authors.

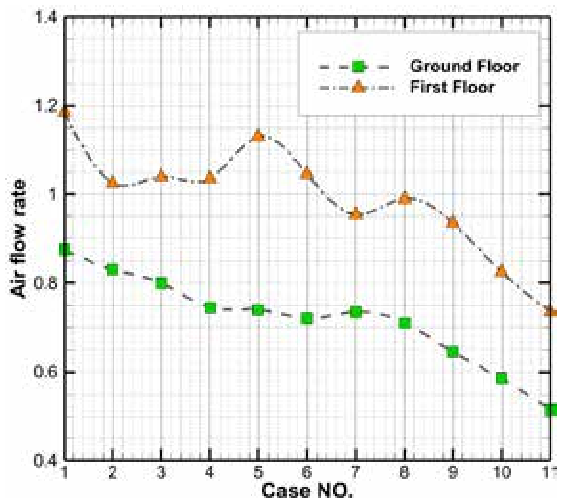

Fig. 14. Air flow changes in the ground floor and first floor rooms in case examples. Source: Authors.

Therefore, the process of increasing ventilation efficiency by changing the pattern of stretching the yard from perpendicular to the wind to along the wind can be clearly seen in this diagram.

- Contrary to the significant differences that were observed in the values of speed, flow rate, and air age in the rooms on the ground and first floors in the case samples, this issue was not observed in connection with the ventilation efficiency in the case samples; In other words, the ventilation efficiency changes in the examined rooms on the ground floor and the first floor of the case samples are similar to each other

Eq. (4) $$T_m = \frac{V}{Q}$$

Eq. (5) $$T_r = 2(T_m)$$

Eq. (6) $$\varepsilon = \frac{T_m}{T_r} \times 100$$

and very little difference has been observed in this regard between the two investigated rooms in the case samples.

Discussion

The main goal of this research is to determine the role of the proportions of the central courtyard on the ventilation flow in the space overlooking the courtyard. For this purpose, the number of 11 case samples including 5 samples with a stretch pattern along the prevailing wind, 5 samples with a stretch pattern perpendicular to the prevailing wind, and a square pattern as a base pattern (taken from the square pattern of Golshan house in Bushehr city) Analysis was selected. The most important research findings can be presented as follows:

- A noticeable difference in air speed, air age, and airflow rate entering the rooms on the ground floor and the first floor of the case samples has been observed; In relation to all the mentioned indicators, the values obtained in the room on the first floor are higher than the values obtained on the ground floor.

- In connection with the ventilation efficiency index, no significant difference was observed in the values obtained on the ground floor and the first floor. The most important finding of the research is the relationship between ventilation efficiency and the elongation of the yard along the prevailing urban wind. This means that by increasing the length of the central courtyard along the prevailing urban wind, the efficiency of ventilation in the interior space located on the main axis of the courtyard also increases. It seems that the cause of this issue is the better direction of the airflow to the desired space due to the extension of the yard along the prevailing urban wind. In such a case, the yard is like a moving corridor for the passage of airflow and causes blinds along the yard; This issue leads to a better direction of the airflow towards the opening of the desired room, and due to the small surface of the wall against the wind, a large part of the passing air enters the room in the form of airflow. Therefore, with the increase in airflow rate, the ventilation efficiency in the room also increases. On the other hand, in case samples with elongation in the direction perpendicular to the wind, the airflow passing through the yard collides with a larger surface of the wall in front of it and a large part of its kinetic energy is damped due to the collision with this rigid wall. This issue reduces the flow of air entering the room and finally reduces the efficiency of ventilation in case samples with vertical stretching to the prevailing urban wind.

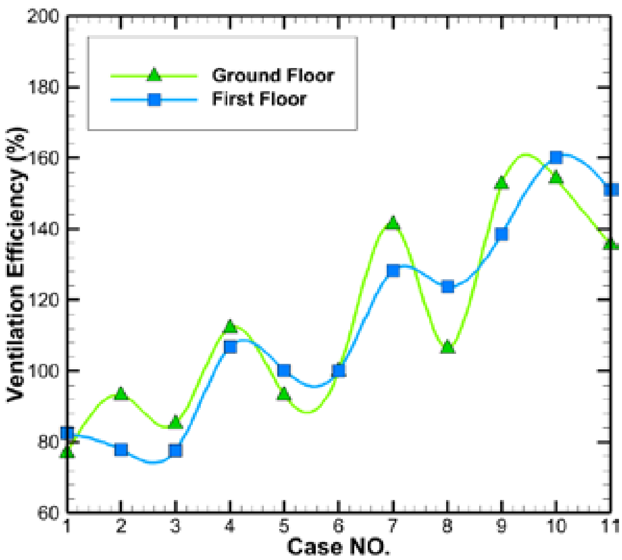

Fig. 15. Ventilation efficiency values for each of the rooms on the ground and first floors of the case examples. Source: Authors.

In the end, future research can be examined from two aspects:

1- The application of simulation in buildings in southern Iran and data collection for other central courtyard houses in the region.

2- The need to solve not only technical problems but also socio-cultural problems in preserving the shape Yard housing in the hot and humid region of southern Iran for the use of the residents of this region.

References list

• Abro, R. S. (1994). Recognition of passive cooling techniques. *Renewable Energy, 5*(5-8), 1143-1146. https://doi.org/10.1016/0960-1481(94)90142-2

• Fathy, H., Shearer,W., Sultan, A. (1986). *Natural Energy and Vernacular Architecture: Principles and Exampleswith Reference to Hot Arid Climates.* University of Chicago Press.

• Heidari, A. A., & Eskandari, H. (2022). Impact of inlet and outlet opening height variation on the air quality and ventilation efficiency in the on-top wind catcher buildings: A CFD simulation. *Science and Technology for the Built Environment, 28*(10), 1420-1438. https://doi.org/10.1080/23744731.2022.2089592

• Khaksefidi, S., Vasigh, S., & Taban, M. (2020). Proper design of the central courtyard in residential areas against Sadobist-roz-e winds in Zabol using CFD analysis. *Spatial analysis environmental hazarts, 7*(1), 197-212. SID. https://sid.ir/paper/407839/en

• Lopez-Cabeza, V. P., Rivera-Gomez, C., Roa-Fernandez, J., Hernandez-Valencia, M., & Herrera-Limones, R. (2023). Effect of thermal inertia and natural ventilation on user comfort in courtyards under warm summer conditions. *Building and Environment, 228*, 109812. https://doi.org/10.1016/j.buildenv.2022.109812

• Mardani, A., & Roasaei, A. (2021). The pattern effect of central courtyard geometric on the air flow in traditional houses of Shushtar. *Studies on iranian islamic city, 12*(43), 71-80. https://dorl.net/dor/20.1001.1.2228639.1399.10.40.5.9

• Moonen, P., Dorer, V., & Carmeliet, J. (2011). Evaluation of the ventilation potential of courtyards and urban street canyons using RANS and LES. *Wind Engineering and Industrial Aerodynamics, 99*(4), 414-423. https://doi.org/10.1016/j.jweia.2010.12.012

• Nikghadam, N. (2015). Climatic Patterns of Functional Spaces in Vernacular Houses of Bushehr (By Grounded Theory). *Bagh-e Nazar, 12*(32), 77-90. https://sid.ir/paper/125636/fa

• Nikghadam, N. (2016). Airflow and radiation impact on moderating heat conditions in the Bushehr houses (Case study: Golshan House). *Journal of Iranian Architecture & Urbanism, 7*(2), 29-46. https://doi.org/10.30475/isau.2017.62028

• Nosek, S., Klukova, Z., Jakubcova, M., & Janour, Z. (2022). The effect of courtyard buildings on the ventilation of street canyons: A wind-tunnel study. *Wind Engineering and Industrial Aerodynamics, 220*, 104885. https://doi.org/10.1016/j.jweia.2021.104885

• Rahai, O. (2021). Investigation of air flow pattern in the central courtyard in Qajar houses of Isfahan by CFD method. *Sustainable Architecture and Urban Design, 9*(2), 25-46. https://doi.org/10.22061/jsaud.2021.6012.1597

• Shaeri, J., Yaghoobi, M., Aliabadi, M., & vakilinazhad, R. (2018). Experimental Study of temperature, relative humidity and wind speed of traditional houses at hot and humid climate of Iran (Case study: Tabib and Nozari houses in Bushehr). *Fine Arts: Architecture & Urban Planning, 22*(4), 93-105. https://doi.org/10.22059/jfaup.2018.229533.671660

• Soflaei, F., Shokouhian, M., & Shemirani, S. M. M. (2016). Traditional Iranian courtyards as microclimate modifiers by considering orientation, dimensions, and proportions. *Frontiers of Architectural Research, 5*(2), 225-238. https://doi.org/10.1016/j.foar.2016.02.002

• Sharples, S., & Bensalem, R. J. S. E. (2001). Airflow in courtyard and atrium buildings in the urban environment: A wind tunnel study. *Solar Energy, 70*(3), 237-244. https://doi.org/10.1016/S0038-092X(00)00092-X

• Taleghani, M., Tenpierik, M., van den Dobbelsteen, A., & Sailor, D. J. (2014). Heat in courtyards: A validated and calibrated parametric study of heat mitigation strategies for urban courtyards in the Netherlands. *Solar Energy, 103*, 108-124. https://doi.org/10.1016/j.solener.2014.01.033

• Zamani, Z., Heidari, S., & Hanachi, P. (2018). Reviewing the thermal and microclimatic function of courtyards. *Renewable and Sustainable Energy Reviews, 93*, 580-595. https://doi.org/10.1016/j.rser.2018.05.055

• Zhu, J., Feng, J., Lu, J., Chen, Y., Li, W., Lian, P., & Zhao, X. (2023). A review of the influence of courtyard geometry and orientation on microclimate. *Building and Environment, 236,* 110269. https://doi.org/10.1016/j.buildenv.2023.110269

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The Effect of Yard Proportions and Length on Indoor Ventilation Efficiency in Central Courtyard Houses in Hot and Humid Climates

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