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Behavior Analysis of Wind Hydrodynamics in the Central Courtyard of Hot and Dry Climate Settlement Based on the Length to Height Ratio (Case Study: Kashan City)

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ABSTRACT: One of the ways to achieve high energy efficiency in buildings and an effective system is to utilize local architectural experiences. In this connection, the central courtyard is an element that was used in the past to create comfort in the hot and dry climates of Kashan, Iran. A large part of the literature in the past has focused on this space and investigated factors such as height, length, and presence of water in the courtyard, which are directly related to the studied space. This article concerns the hydrodynamic behavior of the wind under the effects of the length-to-height ratio to reduce the temperature of settlements in Kashan's hot and dry climate, aiming to yield the highest efficiency from this element. This study uses Fluent, Energy Plus, and Open Studio software using a descriptive-analytical method to analyze the data. In the end, it is determined that since the prevalent wind in Kashan comes from a northeast front, it can be utilized by placing the longitudinal direction of the central courtyard on its path. In addition, the optimal state in all models suggests the central courtyard has experienced a length-to-height ratio of 1to4, followed by a ratio of 1to5.

Keywords: *Hydrodynamic behavior; Average interior temperature; Central Yard; Hot and dry climate.*

INTRODUCTION

It is known that climate has a key role in determining and forming architecture and cities. One would say that one of the most effective factors affecting designs is climate, as it has had a considerable effect on every building and architectural element, the interiority of the spaces, and all humans' manners of life (Hassangholi Nejad & Mofidi-Shamirani, 2019). In Iran, where large parts involve hot and dry climates, there should be specific solutions for the desirability and viability of the residences, as traditional Iranian architecture used various ways to provide comfort for the occupants of buildings. In old cities of Iran, there are connecting spaces such as central courtyards with multiple forms, functions, and meanings, which help link spaces and architectural elements together (Central courtyards use natural elements of light, water, wind, and nature) so that the residents' qualitative level of life is increased (Etesam et al., 2011). Climate-based architecture in hot and dry climates is characterized by a central courtyard, which is assumed to be a critical space for Kashan's residential buildings. As a passive solution to provide thermal comfort in the building, this space serves as a safe space that would help create natural ventilation, daylight, and visual communications with nature. Environmentally, a central courtyard, as an element of architecture, has played its role in protecting the residents under undesirable climatic and environmental conditions via using passive energy supply systems in various regions. This element uses evaporative cooling systems, passing ventilation, radiation cooling, and shading through cooling down and reducing the cooling load of the building (Vakilinejad et al., 2013). In this regard, structural components of the central courtyard, including the general form, the courtyard's proportions, and the formative structure of its walls, have a great role in static cooling (Prelgauskas, 2003, 36). In this research, the central courtyard of residential buildings in Kashan City's hot and dry environment is considered, along with the assumption that the courtyard would be rectangular and long enough to face the prevailing wind.

Additionally, it is believed that figuring out the ideal height

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ratio based on the length of the central courtyard and its impact on the hydrodynamic behavior of the wind will lower the air temperature there. It investigates an appropriate response to the issue of what impact this ratio has on the hydrodynamic behavior of the wind inside the yard and what is the best state for it to do so to lower the temperature inside the yard. Since the center courtyard serves as a transitional zone and enhances comfort by altering the microclimate inside the structure and accelerating air movement inside the building, it is an effective design choice in hot and dry regions. Thus, by providing an ideal ratio, the answers to the questions above to lower the air temperature inside the courtyard can enhance one of the passive options for supplying thermal comfort in native design, namely the central courtyard.

MATERIALS AND METHODS

As stated, this study aimed to investigate the effects of length-to-height proportions of the central courtyard on airflow in hot and dry climates. The methodology of this study is descriptive-analytical. It uses the proposed methods to investigate the central courtyard's role in modifying the intended climate using library studies, modeling, and computer simulations of central courtyards of traditional houses in Iran's dry and hot climates (Kashan city). Thus, given the structural nature of the research framework, the courtyards with common length-to-height ratios were modeled in the Fluent software, and their velocity and wind contours were compared to those of other models.

Climatic Data Used

To simulate the thermal performance of the model prepared under similar climatic conditions in the city of Kashan, Kashan's climatic data files, formatted EPW, were used, which show climatic data on an hourly basis. This file is one of the several available climatic files in Iran, which has been uploaded on the site of the Energy Plus software developers. Repository of free climate data for building performance simulation From the Creators of the EPW. (Creators of the EPW, 2022).

Thermal Comfort Limits for The Residents of Kashan City

Consistent with the studies conducted on the residents of the city of Kashan and the temporal limits and thermal comfort ranges, it is determined that the said limits for the city of Kahan range from 27-218ºC in summer to 26-204ºC in winter. In contrast, the relative humidity ranges from 18-53% (Sadeghi Ravesh & Tabatabaei, 2009).

Wind Situation in The City of Kashan

According to Kashan's meteorological data, the average wind velocity at the Synoptic Station of Golbad in springs is clocked at 2,94 m/s, 3,97 m/s for the summers. As a result, the average wind velocity in the first six months of the year is estimated to be 3,455 m/s, with the desirable wind direction coming from the northeast.

Literature Review

Hajian et al. examined the spatial effect of the courtyard and its contribution to the formation of traditional Iranian houses in four examples of houses in the city of Kashan in their study, "The effect of the courtyard in the formation of the configuration of traditional Iranian houses in Kashan" (Hajian et al., 2020). Hanif investigated the physical and spiritual qualities of Kashan homes during the Qajar era in a work titled "The notion of occupancy and its influence on the courtyards of Iranian houses: a case study of Kashan houses in the Qajar period" (Hanif, 2017). In an essay titled "The Effect of the Central Courtyard Pattern in Adjusting the Hot and Dry Climate Conditions of Kashan Houses," Jafarian and Monsafi Propari demonstrate that in addition to the spatial division and organization of the house's spaces, the presence of a central yard with the right proportions has significantly improved and controlled the climatic conditions in traditional houses of hot and dry climates, especially Kashan houses, and has led to the adjustment of the climatic conditions in winter and summer (Jafarian & Monsafi Prapari, 2021). In an article titled "Optimum design of the central courtyard in residential buildings against the 120-day wind of Zabul based on CFD analysis," Khaksefidi and others aim to find the best placement and appropriate geometrical shape of the buildings in the central courtyard type as well as ways to lessen wind speed, at least in a defined central courtyard area, and to lessen pollution emission in the central courtyard, which is amplified by the rotation (Khaksefidi et al., 2019). In a study by Mazaheri and colleagues titled "Analysis of the role of the yard in the spatial structure of Iranian houses using the space syntax method," the spatial organization of various examples of Iranian homes is analyzed. The common characteristics and elements of the homes are explained, which show the most characteristics of the courtyard in the architectural space of these homes (Mazaheri et al., 2017). In an article titled "The role of the central courtyard pattern in adjusting the harsh conditions of the hot and dry climate of the Yazd region," Zarei and Mir Dehghan examined the impact of the central courtyard design of houses in Yazd and determined how the ratio of the central courtyard to the walls affected the region's harsh hot and dry climate (Zarei & Mirdehghan, 2015).

The literature on the central courtyard has specifically addressed its architectural features, with some studies dealing with the courtyards' thermal comfort and static cooling. One of these researches has analyzed structural parameters and courtyard design proportions in Mexico and Spain. In the fourth chapter of the book, "Responding Environments," with the title of micro-climate, Bentley et al. have proposed a way to reciprocally analyze the city and the climate, which stresses two climatic elements of radiation and wind (Bently et al., 2003). One of the major features of houses in this region is their interiority, inspired by the regional climate. This has caused the spaces to form on one or four sides of the central courtyard. The courtyard is the most important space for the supply of light, ventilation, internal communication, and other functions. The placement of spaces built around the courtyard, especially in large houses, and enclosed on four sides by rooms or walls, have rendered these spaces to be called central courtyards (Soltanzadeh, 2011). Soheili Fard et al. used the Ecotect software to study the interaction of the Abbasian house in Kashan city with solar energy (Soheili Fard et al., 2013). CFD-based simulation is another method to study the interaction between the climate and residential architecture. Cristiano et al. used this technique to investigate the thermal comfort conditions in the internal environment of the traditional Minahasa houses (Kristianto et al., 2014). Nasrollahi et al. investigated the effects of climatic elements in Iranian architecture on the central courtyards in four samples of Kashan's houses in hot and dry regions (Nasrollahi et al., 2014). Arabi and Behbahani Nejad (2013) also examined the central courtyard space in Kahan's hot and dry climate (Arabi & Behbahani Nejad, 2013).

Functions of the Central Courtyard

As stated above, considering the review of climatic problems and attention to the role of the courtyard and its elements, it is concluded that a courtyard is an open space in a house that serves as the most important part of the entrance space. It is a room with no roof but has advantages for the family members. In this space, one can enjoy the nature, trees, and humidity of the water ponds, communication and companionship with guests, and the comfort caused by stillness and privacy. Other house spaces directly related to the courtyard include porches and rooms surrounding corridors and stairways. Around the courtyards are various rooms in direct contact with water, plants, and fresh air, as the surrounding spaces also include three and five-door rooms, halls, wind towers, sash, balconies, and corners (Fig 1) (Kateb, 2005, 42).

The people of the desert have always tried to overcome these extreme climatic conditions and have employed various techniques to overcome these problems (Table 1 & 2). The idea of interior-based houses was perhaps the best answer to these

Fig. 1: Image of the central courtyards.

Table 1: Local architectural characteristics of the hot and dry climate (Motazedian, 2010).

Type of climate	Type of materials	Complex fabric	Direction	Material’s	Design factor
Hot and dry	High thermal capacity	Dense	S-SE	Clear	Use of shade and increase of humidity

Table 2: Climatic problems of desert cities (Bukharai, 2010).

Climatic phenomenon	Type of effects	Level of effects
Wind and rain	Wind with dust	In summers
	Oblique rain	-
	Over 200 spots of rain	-
Level of radiation	Radiation intensity	Very high
Low temperature and freezing	Melting and freezing	months 1-2
	Temperature rate below 5	months by nights 3-4
	Temperature rate below 0	Sometimes by winter nights
Humidity	Decay	-
	Condensate	Possibly 2-3 months
	Humid	-

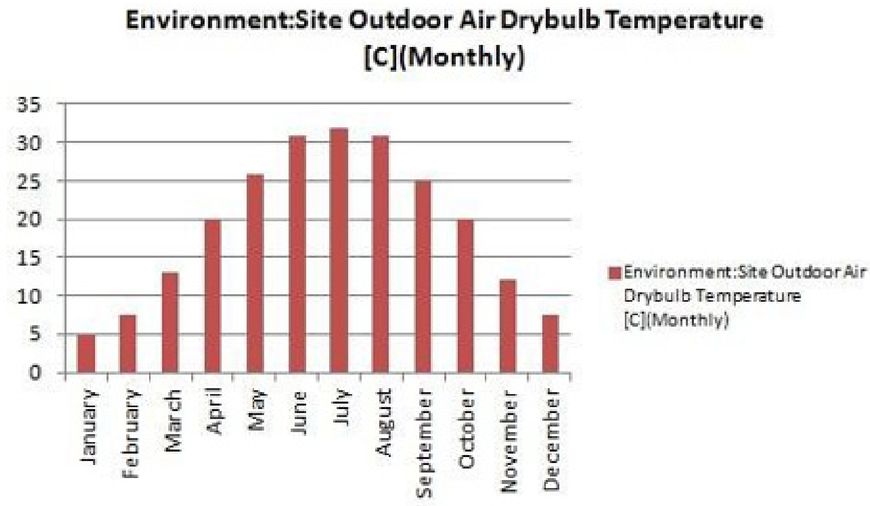


Fig. 2: Monthly temperature of Kashan, the output of Energy Plus software

problems, with the central courtyard becoming a turning point of these techniques. The residential architecture of the central regions of Iran, such as Yazd, Isfahan, Kashan, and Shiraz, is interior-based, with different spaces of houses in these regions being organized in a certain order and different building directions; in the meantime, the way central courtyards have been organized and the type of spaces forming these houses can be regarded as major factors contributing to the division of these residential houses (Forghani, 2011).

Ventilation in the Central Courtyard

Natural ventilation is intensely dependent on the opening facilities of the buildings. The use of mechanical systems has made this type of ventilation be ignored. However, one should pay attention that using natural ventilation increases the air quality inside the house and saves energy consumption. As a result, natural ventilation can be regarded as a major strategy to achieve a green building. Consistent with the literature and wind towers, some other measures, such as atriums, central courtyards, domed roofs, and windbreaker walls, are parts of the buildings. If these measures are properly adopted in a building, they will considerably impact the quality of the air inside. It was also determined that the central courtyard, as a transfer zone, modifies the micro-climate within the building scope, increases the airflow inside the building, and improves comfort conditions. This causes the central courtyard in hot and dry climates to become an effective strategy. In this type of climate, wind direction towards internal space is essential in summer to modify heat and humidity and improve thermal comfort. This strategy is highly effective and cost-saving under these conditions (Tabesh & Sertyesilisik, 2015).

Investigation of Yard Proportions on Natural Ventilation

This section considers a fictitious instance of the central courtyard model existing in Iran's hot and dry climate (Fig 2). All models have a courtyard with a fixed width, height, and variable length. Wind calculations are done up to 10 m above the ground. The temperature of the ground and building surfaces were modeled in each model using the Open Studio software environment. The temperature of the relevant model's internal and external surfaces was then calculated using the Energy Plus software. Finally, the models were modeled in the Ansys Fluent software, which calculated their temperature and airflow rate. The yard is rectangular, and according to the Energy Plus software, its length is assumed to be fixed in the direction of the predominant wind. The mean air speed is 3.455 m/s, and its temperature is 33.6 degrees Celsius, equivalent to the monthly temperature of Kashan city in July.

The ratio of the yard's length to the building's height is regarded as a variable, and the ratios given for the central yard are 1 to 1, 1 to 2, 1 to 3, 1to 4,1 to 5, 1 to 6, 1 to 7, 1to 8, 1 to 9 and 1to 10 (Table 3).

RESULT AND DISCUSSION

We first model in the Open Studio software environment, then utilize the Energy Plus software to compute the temperature of the appropriate model's internal and external surfaces. Finally, we used Ansys Fluent software to model the models and quantify the temperature and airflow velocity within them (Table 1).

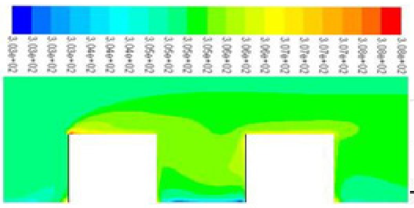
Length to height ratio 1 to1, in this case, the wind flow contour the mode has three general flows: one was flowing from the top of the yard, which changes its horizontal direction and travels over the yard more quickly due to the collision of the airflow with the first volume, but has minimal influence on the airflow inside the yard. It moves through the rooftops and the yard. The second flow occurs within the yard. It's a feeble stream that impacts the upper half of the yard and doesn't reach the

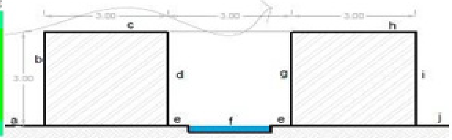
Table 3: Investigation of yard proportions on natural ventilation, July, Kashan city (Open Studio)

(Velosity) ‹m/s (Temperature) ‹K	Length to height ratio

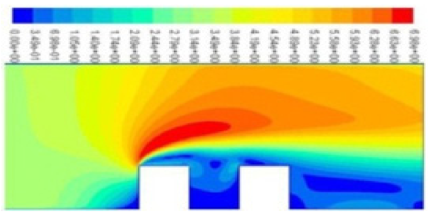
1:1

(ºC) Temperature Exterior	(ºC) Temperature Interior	surface	(ºC)Temperature Exterior	(ºC)Temperature Interior	Surface
20	-	f	30	-	a
35.7	29.32	g	36.2	29.37	b
43.24	30.72	h	43.24	30.74	c
36.5	29.39	i	36.1	29.34	d
30	-	j	24.28	-	e





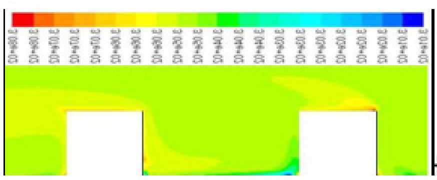
Temperature

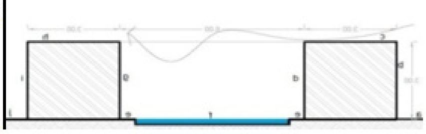


Velocity

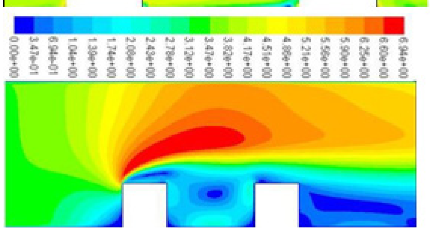
1:2

(ºC) Temperature Exterior	(ºC) Temperature Interior	Surface	(ºC)Temperature Exterior	(ºC)Temperature Interior	Surface
20	-	f	30	-	a
36.02	29.60	g	36.17	29.62	b
43.27	31.05	h	43.27	31.05	c
36.54	29.64	i	36.39	29.63	d
30	-	j	25.11	-	e



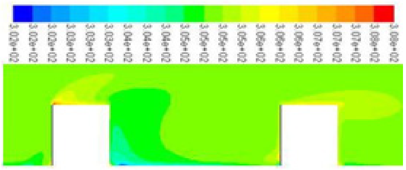
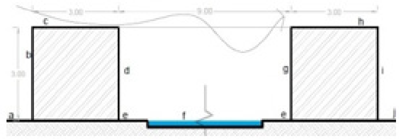
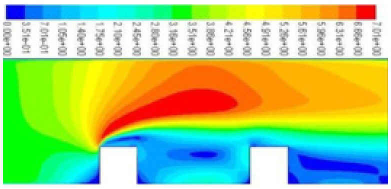
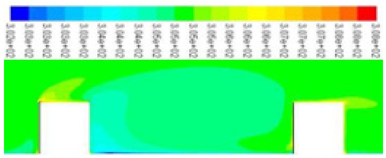
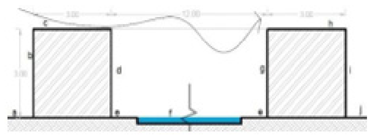
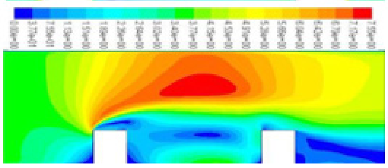
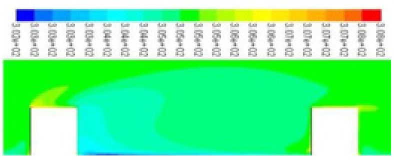
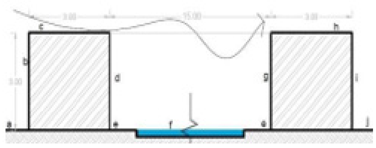
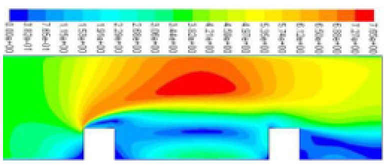
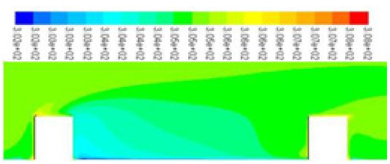
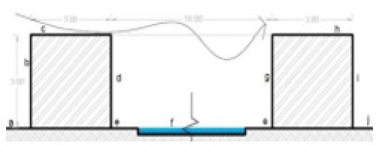
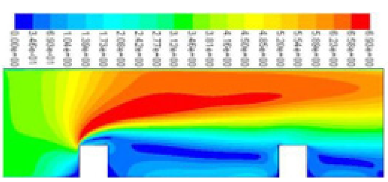


Temperature

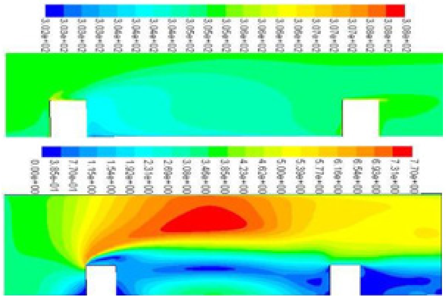
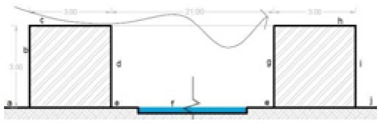
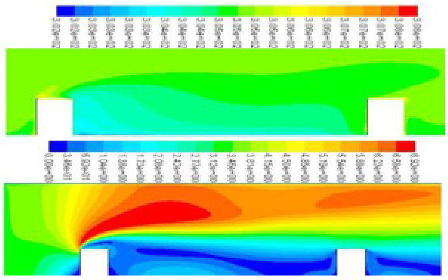
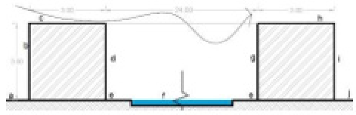
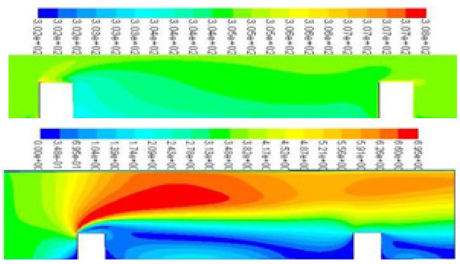
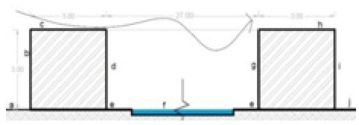
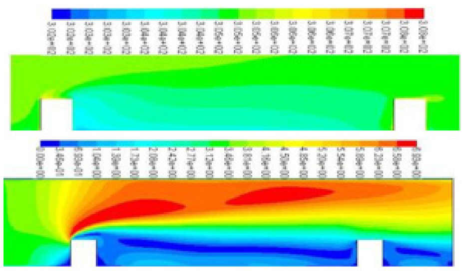
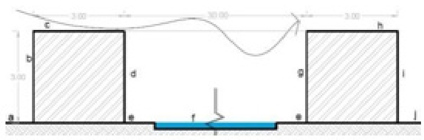
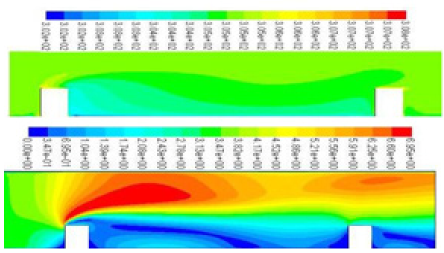
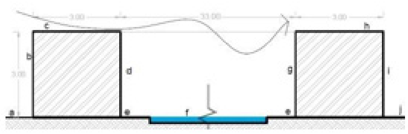


Velocity

Continiue of Table 3: Investigation of yard proportions on natural ventilation, July, Kashan city (Open Studio)

(Velosity) ،m/s (Temperature) ،K		Length to height ratio
  	Temperature Velocity	**1:3**
  	Temperature Velocity	**1:4**
  	Temperature Velocity	**1:5**
  	Temperature Velocity	**1:6**

Continiue of Table 3: Investigation of yard proportions on natural ventilation, July, Kashan city (Open Studio)

(Velocity) ،m/s (Temperature) ،K			Length to height ratio
		Temperature Velocity	7;1
		Temperature Velocity	1:8
		Temperature Velocity	1:9
		Temperature Velocity	1:10
		Temperature Velocity	1:11

ground. The air circulates and rotates above the yard due to this circulation. The third current is the shadow cast by the yard's second volume, generated by the lack of another volume behind the structure (due to negative pressure). The flow of the wind shadow. It has a longer length and little to no wind resistance. The center of this stream is half the height of the building and has a velocity of around zero. In this situation, a thin layer of air forms on the roofs at a low pace, and the air temperature inside the central yard drops by less than 1 degree Celsius when compared to the ambient temperature.

Length to height ratio 1 to 2, When the length of the yard doubles, a wind ring (static ring) forms in the middle, causing more air to flow in the yard than when the ratio is 1: 1. The wind speed is higher on the building surfaces next to the yard and the yard floor than in the middle of the ring. The wind's shadow behind the volume is now longer and closer to the ground than previously. The very hot roof temperature altered its temperature curve the most. Only at the yard's floor, where the air is adjacent to the pond, can we notice a 1 ° C drop in temperature.

Length to height ratio 1 to 3, The airflow inside the yard is slanted from square to rectangular in this scenario. The air near the yard's floor and the building surface facing the wind is faster than the air in the yard's middle and the surfaces behind the wind. The maximum wind speed is larger than in examples 1 and 2, and the speed under the shadow of the volume wind also increases slightly. The second volume of the roof's practically static air layer is considerably less, and the roof is exposed to airflow, which minimizes the temperature impacts on the roofs in the temperature diagram, which is one of the most efficient factors in cooling the room.

Length to height ratio 1 to 4, In this example, we witness wind flow with a speed of about 3 m / s near the yard floor (next to the pond) and a speed of around s / m 2 towards the windward surfaces. In general, wind flow meters at the end of the yard are faster; low-velocity currents on the second volume roof are eliminated. The maximum wind speed occurs in the longitudinal center of the yard at a speed of about 1 meter per second compared to its previous state. We see a drop in temperature of about 1 ° C, especially in the backyard area

Length to height ratio 1 to 5, In this case, the shadow of the wind on the yard becomes more stretched, and the wind flow in the yard is limited to the yard's floor and its end. The second volume's roof is exposed to the wind and receives no wind shadow. The maximum wind and temperature are identical to the four-to-one model.

Length to height ratio 1 to 6, The maximum speed is decreased to about the size of the second building. The wind's shadow in the middle of the yard is greater and almost completely covers the entire yard, reducing the wind speed inside. Because of the pressure of the airflow passing through the yard, which tends to penetrate the yard from the end, the static air range (0 to 69.0) s / m at the end of the yard has a sitting facing the yard's floor. In the central courtyard, the air temperature drops by one degree.

Length to height ratio 1 to 7, Airflow corresponding to average wind speed in the environment (m/s) 3 also drops that it is caused by lowering the height of the current passing through the yard, as a result of which the height of the wind shadow behind the second volume is also reduced. The yard's still air region is divided into two sections, one flowing faster on the side. The wind shapes the back surfaces. In this situation, the second volume operates similarly to the first, deflecting the impact current upwards more swiftly despite its weak outlines. The largest drop in air temperature is around 1 degree behind the initial volume.

Length to height ratio 1 to 8, We witness the propensity of airflow going through the yard into it as the length of the yard increases in ratios of 8 and greater, causing the proximity of streams with speeds over 3 s / m on the second roof. Currents travel at a rate of 1 / 7-3 s / m around the second roof (courtyard side and behind the volume). The velocity of the currents is close to zero at the bottom of the yard and the end of the yard; however, there is a higher current in the middle of the yard and adjacent to the back-to-back surfaces. In addition, the outlines generated by the second volume are more intense than those created by the first.

Length to height ratio 1 to 9; in this situation, the airflow is lower at the yard's end, causing a flow in a section of the yard. In addition, the maximum wind speed occurs when the wind is at its strongest. The second volume creates greater curves in the yard's middle and near the back surfaces, which is windward. The temperature is higher, and the speed is slower near the end of the yard than at the beginning.

Length to height ratio 1 to 10, 1 to 11, The shadow of the wind flow on the yard is diminished, and the wind affects its end parts, with a ratio of 1 to 10 and 1 to 11. Also witnessed intensification (Bold orange color). We are the counters of the airflow velocity passing through the top of the yard and the formation of independent wind currents of the second volume.

Summary

The maximum wind speed rises in the 1to3, 1to5, 1to4, and 1to7 to modes (more than 7 meters per second). The top speed doesn't alter much after that. The height of windbreaks in this environment may be determined by studying the maximum wind flow on the yard and roof of the second volume (modes 1to1 and 1to5 to), which travels through a height of roughly twice the height of the structure. This flow has a very low height from the roof because of the initial volume's contact with a wall, which may be taken advantage of in smart designs. For all modes, the maximum speed after reaching the first volume is around double the ambient wind speed. Models with ratios of 1to8 to and higher are being examined for the courtyards of large homes; nevertheless, one drawback of these designs may be the extent to which the yard occupies the infrastructure. Since the prevalent wind in Kashan comes from a northeast front, it can be utilized by placing the longitudinal direction of the central courtyard on its path. In addition, as table 3 suggest, the optimal state in all models suggests the central courtyard has experienced a length-to-height ratio of 1to4, followed by a ratio of 1to5 to.

CONCLUSION

Utilizing regional architectural expertise will result in a more energy-efficient building and effective system. Due to the benefits of shade, water, and vegetation within, as well as depending on the kind of walls, height, and proportions, the central courtyards can lower the air temperature on the hot days of Iran's hot and dry environment. On the other side, in the early spring and late fall, air currents created in the yard can be employed as natural ventilation for cooling. Given that research in the field of the central courtyard has mostly focused on its architectural features, including case studies, impacts, analyses of the courtyard's function concerning climatic software, and the best layout for regulating climate, considering the aerial data of Kashan city and the location of the length of the yard in the direction of the prevailing wind, it was analyzed using Energy Plus and Fluent software. The length of the central courtyard was placed as a variable and analyzed with different ratios to investigate the hydrodynamic behavior of the wind in the central courtyard in reducing the air temperature of residential homes in the hot and dry climate of Kashan city. Even though this research's simulations and analyses haven't been done for a specific structure and are only applicable to hot, dry regions with rectangular center courtyards, all models take the same wind speed and temperature into account. They do not account for additional variables like the type of material used to construct the yard wall.

But as a consequence, it was discovered that the usage of central courtyards with a length-to-height ratio of 4 to 1 and, after that, a ratio of 5 to 1 is the best option for all models. Because the north-easterly breeze is the one that blows most frequently in Kashan city during the hot summer months, the yard may be exploited to its maximum potential by orienting its longitudinal axis in this direction. The outcome of this study is significant because it demonstrates that the air temperature in the central courtyard drops by around 1 °C in all models. The air temperature felt by users in the ideal model of the yard, however, is roughly 3 to 6 degrees lower than the ambient air temperature due to other factors, including shade and wind speed (every 1 meter second of wind can lower the comfort temperature range by 3 °C). This problem can enhance the functionality of the center courtyard, one of the passive solutions for thermal comfort in native design. Finally, it is recommended that future studies investigate the central courtyard in other climates, analyze how it behaves in lowering interior temperatures in conjunction with other influencing factors, and analyze the impact of the geometry of the central courtyard on the passing air flow next to the walls and floor.

AUTHOR CONTRIBUTIONS

M. Karbasforoushha performed the literature review and model design, analyzed and interpreted the data, and prepared the manuscript text and edition. F. Habib and H. Zabihi prepared the manuscript text and manuscript edition. Compiled the data and manuscript preparation.

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CONFLICT OF INTERESt

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication, falsification, double publication and, or submission, and redundancy, have been completely witnessed by the authors.

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