KIEAE Journal, Vol. 21, No. 5, Oct. 2021, pp.25-32.

Check for updates

KIEAE Journal

Korea Institute of Ecological Architecture and Environment

111

A Numerical Experiment on the Effect of Stone Fences on the Wind Stream Formation in Vernacular Architecture of Jeju

Muhammad Uzair Mehmood* · Jae Young Lee** · Hyun Joo Han***

* Researcher, Dept. of Nuclear and Energy Engineering, Jeju National Univ., South Korea (uzairmehmood001@jejunu.ac.kr)
** Coauthor, Professor, School of Mechanical and Control Engineering, Handong Global Univ., South Korea (jylee7@handong.edu)
*** Corresponding author, Professor, Dept. of Architectural Engineering, Jeju National Univ., South Korea (hjhan@jejunu.ac.kr)

ABSTRACT

Purpose: A three-building thatched residence with stone fences representing the traditional housing architecture in Jeju has been studied with the help of simulation tools. The main goal of this study was to identify the role of stone fences on the overall wind flow through the three building structures. Especially, the physical dimensions of the fence (height, size and, the number of holes) along with its distance away from the building wall (façade) have been extensively studied concerning its effect on the formation of wind streams as the flow develops interacting with its surroundings (building elements, ground, etc.). **Method:** Stone fences installed along the periphery of a traditional residence (comprised of three buildings each with a thatched roof) can significantly influence the passage of wind through its internal region. Various cases have been explored while changing the key parameters influencing wind flows, such as height and holes of fences. **Result:** The results provide clear evidence that holes in stone fences provides a more uniform path for the wind flow as compared to a fence without any holes. Moreover, the wind speed can be greatly influenced by the change in fence height and the presence of holes in it.

KEYWORD

Stone Fences
Porosity
Vernacular Arechitecture
Numerical Experiment
Wind Flow

ACCEPTANCE INFO

Received Oct. 6, 2021
Final revision received Oct. 26, 2021
Accepted Oct. 27, 2021

1. Introduction

Jeju Island, an oval shape volcanic island, is located southwest of the Korean peninsula. It has a temperate climate with temperatures that rarely drop below the freezing point. Like in other parts of the world, the vernacular architecture of Jeju has been the presentation and transmission of the architectural heritage of the past, reflecting cultural tradition, significant environmental features, and locally available natural resources. It has been developed over time, responding to human needs, cultural evolution, and changing demographics.

This work investigates the characteristics of its vernacular design of a typical residential private house located in the southeast of Jeju Island. Among many of its distinctive features, the major concern of this study was to analyze the effect of stone fences surrounding the residential buildings when the wind blows against the fences and stream through the building structures. Especially, the distance between the fence and the façade of the residential building (house) has been thoroughly analyzed concerning its effect on the formation of wind streams that pass through different building elements from the fence to the rear of the building. Although there have been some attempts to study the role of stone fences typical of vernacular architecture in Jeju, most of them are short of providing detailed analyses in a more systematic perspective as dealt with in this study (especially, in aerodynamic point of view) [1-6].

Different types of fences such as wind breaks, sand fences have been used along with traditional fences to either reduce the velocity of incoming wind or to reduce the emission of particles. Chen et al. studied a porous fence with deflector and compared the results with a traditional wind fence. This fence had deflectors attached next to the holes at a fixed inclination resulting in an overall decrease in wind speed and pressure after the fence. In comparison to a traditional fence, the deflector-porous fence is capable of achieving a maximal reduction of 77%, 38% and 37% in velocity, mean pressure and turbulence intensity [7]. Xin et al. studied the effectiveness of sand control fences in protecting the highways and railways around deserts. The effectiveness of the fence was studied as a function of the fence height and its porosity. For the case study of Gobi buildings in Southern Xinjiang, the authors recommended the optimal fence height to be 2.0-2.5m and a porosity of 10%-15% [8]. Yahya et al. numerically studied the effects of wind direction on the wind flow characteristics of a traditional Malay house. The magnitude of

pISSN 2288-968X, eISSN 2288-9698
https://doi.org/10.12813/kieae.2021.21.5.025

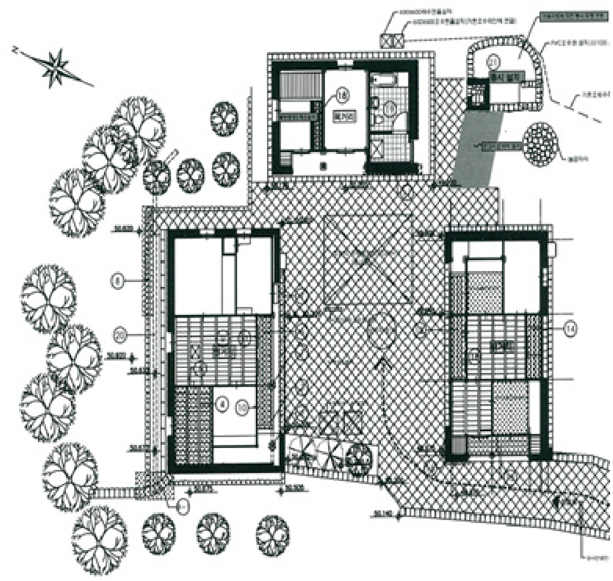

Fig. 1. Floor plan of a traditional residence in Jeju, the "Yang Geum-seok" residence.

pressure coefficient changed significantly with the change in wind directions. The results from the model show that these houses are especially vulnerable to windstorms at oblique angles to the structure [9]. Santiago et al. performed a numerical study of air flow across windbreaks using three different turbulence models. The shelter effect from a wind break can result in a reduction in particle emission in harbours. The authors concluded that a porosity of 0.35 can result in the best shelter effect even at large distances. The wind break with lesser porosity can result in recirculating flow at downstream large distances [10]. These studies gives some valuable information in reference to the aerodaynamical analysis of different types of fence. They are however, quite different in their scope and model configuration as compared to the present study.

2. Simulation and Methodology

The modeling for the simulation was carried out in CREO parametric 3.0. The modeled files were imported into the Ansys Fluent module in STEP format. Within the fluent module, different boundary conditions such as fluid inlet, outlet and the wall surfaces have been defined. All the different surfaces of the model geometry were considered as walls in the simulation definitions.

To get a quick grasp of its effect of a stone fence on the formation of wind streams, a simple model composed of a stone fence and a residential building was analyzed whose results were conducive in understanding the effect of stone walls surrounding the "Yang Geum-seok" residence in its full scale. Especially, the distance between the stone fence and the building façade was

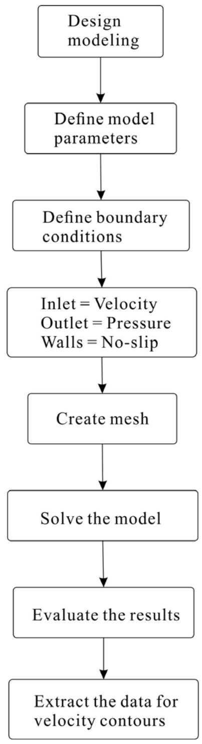

Fig. 2. Flowchart describing simulation procedure

extensively studied as this appears to be the prominent governing factor in the formation of wind streams in and around the various building elements in reality.

2.1 Full scale model

Simulations were carried out by Fluent in analyzing the wind streams in terms of its velocity and the formation of flow patterns in and around the "Yang Geum-seok" residence The modeling for the simulation was carried out in CREO parametric 3.0. The modeled files were imported into the Ansys Fluent module in STEP format. Within the fluent module, different boundary conditions such as fluid inlet, outlet and the wall surfaces have been defined. All the different surfaces of the model geometry were considered as walls in the simulation definitions. Fig. 2. gives the simulation procedure taken in the present numerical analysis.

A simulation model has been designed to accurately calculate the effects of wind as it flows across the three house geometries. Fig. 3. gives the layout of different structures in the model. The dimensions of the model are in accordance with the actual house models for Angeori building. The other two major structures namely Mogeori and Bageori are scaled down with respect to Angeori reflecting the actual dimensions of each building. That is, the models of Mogeori and Bageori have been scaled down, which are 80 and 90 percent of the Angeori building, respectively. Fig. 3. gives the rendered model of all the structures used in the simulation

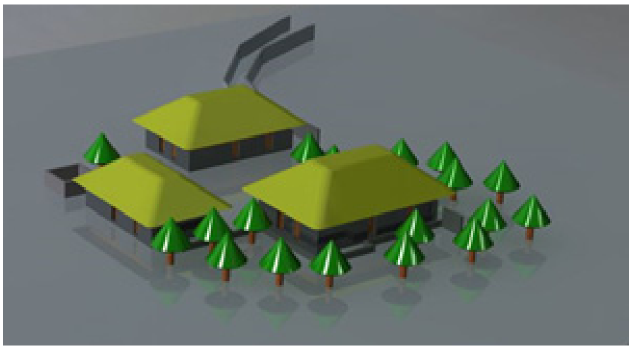

Fig. 3 Rendered simulation model of the “Yang Geum-seok” residence

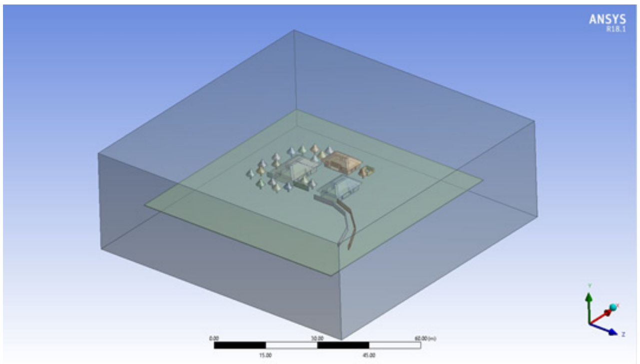

Fig. 4. Model setup within ANSYS

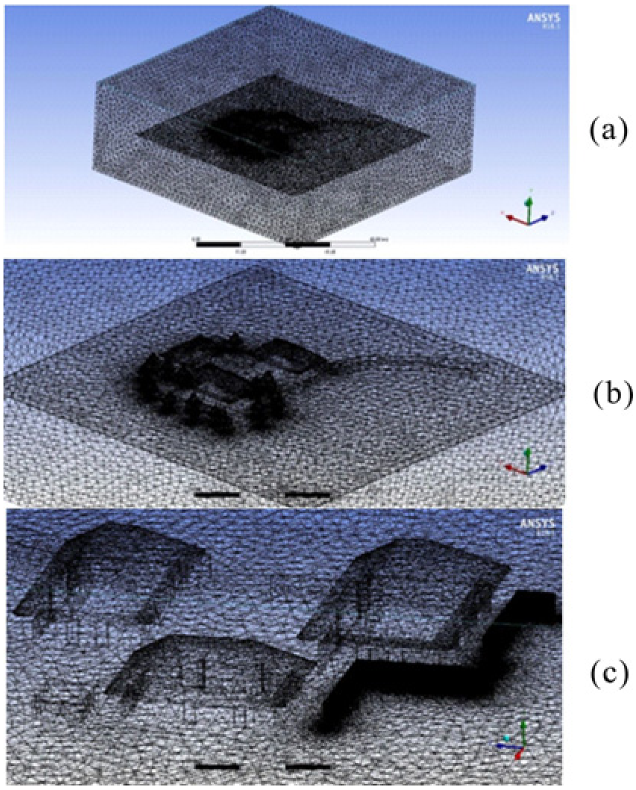

Fig. 5. Meshing representation of all geometrical elements in the model

The no-slip boundary condition was applied to all surfaces of the building structures including ground surface. As the wind flows throught the inlet towards the outlet, the simulation software calculates the overall windflow pattern with respect to the geometry and the wall boundary condition defined for each surface as aforementioned.

Fig. 4. gives the representation of geometry within Ansys. The whole of the geometry is enclosed within a larger fluid geometry.

The last step before calculating the wind flow pattern is to create a mesh for all the geometries in the simulation. The mesh is adaptive in the sense that smaller sized geometries will have a finer mesh size to accurately carry out the calculation as much as possible. Fig. 5. gives the meshing representation of the geometry. Fig. 5.(a) provides the mesh for the complete geometry including the fluid domain and other structures such as the geometry of three houses and fence. Fig. 5. (b) and (c) provide a more enlarged view of these meshed geometries.

The flow direction is along the positive z-axis in the given figures. The airflow speed was assumed to be 3m/s based on the average wind speed in Jeju. That is, 3m/s has been chosen as it is the average value of the wind speed in Jeju, averaged over the years [11]. The behavior of wind flow is observed for two different heights of the northern fence; both with and without the presence of holes in the fence geometry. The diameter of the holes is 0.03m and the distance between the two consecutive holes is 0.27m along the length of the wall and 0.25 m along the height of the wall. This gives roughly 20 holes per square meter (of the fence geometry) in compliance with the hole properties used by Lee and Jeon earlier [2].

2.2 A single fence and a house model

In this section, a simple model comprised of a stone fence and a residential building (house) was developed, which is much simpler than the above-mentioned model based on the “Yang Geum-seok” residence. This model has been considered to study the effect of the change in distance between the fence and the house subject to the same wind field as mentioned above. The fence has height equivalent to the wall height of the house geometry while the length of the fence is twice the length of house. Such a large length will remove the edge effect when observing the behavior of wind streams as it passes the fence.

Analysis has been carried out to examine the effect of the distance between the fence and house as wind blows toward the fence, which runs through the house. It was assumed that the wind initially has the speed of 3m/s and flows uniformly. A total of four different cases were considered for detailed analyses concerning the interaction between wind streams and building structures along with fence geometries. Each case differs from one another by differences in the distance between the fence and the house wall (façade) or by the presence (absence) of holes in the fence.

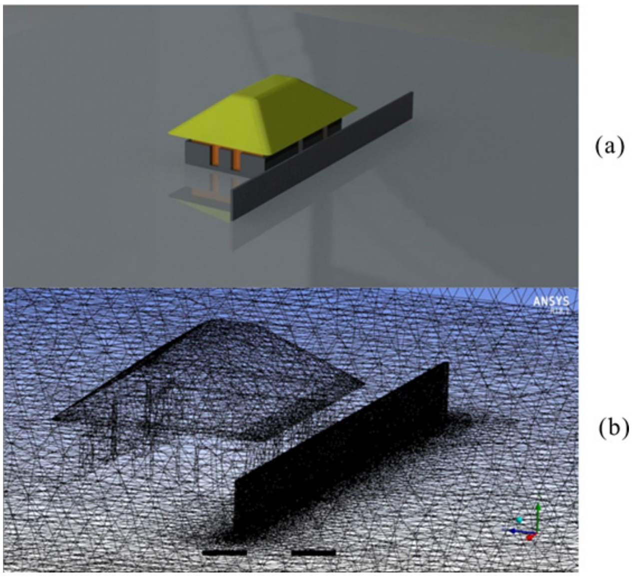

Fig. 6. Computational model: (a) Rendered 3D model, (b) Mesh generated

3. Results and Discussion

3.1 A single fence and house model

Fig. 7 shows the top plane view of wind pattern at different elevations subject to the configuration as given in Fig. 6. The elevations are at a height of 0.25m, 0.5m, 1m and 1.5m from the ground surface, when a solid fence (without holes) of 2 m in height was located at a distance of 0.5m away from the façade of the house. Here, the distances of 0.25m, 0.5m, 1m and 1.5m are used to present the velocity contours at different elevations from the ground surface. The velocity flow across the geometries and the boundary layer effect is described well by these images. The distance is gradually increased from 0.25m to 1.5m. At 0.25m, the section plane is very close to the ground surface and there is a significant decrease in velocity due to the boundary layer. This effect of boundary layer diminishes up to 1.5m. The images are only provided until the elevation of 1.5m after which the effect of boundary layer becomes negligible. Moreover, above this height, the only geoemtries that are visible in the top view countours is the roof of the house.

As shown in this figure, a change in the flow pattern and its strength (speed) can be readily observed with the elevation due to the interaction between viscosity of solid boundaries (fence, ground). As the distance between the wind and ground increases, the effect of nonslip condition (viscous effect) becomes smaller. In the cases of 1m and 1.5m above from the ground, the velocity field of the wind distant from fence and house shows its initial preset value of 3m/s (colored in cyan). The viscous effect on the velocity field can be easily identified as its magnitude (speed) mostly represented by yellow or red.

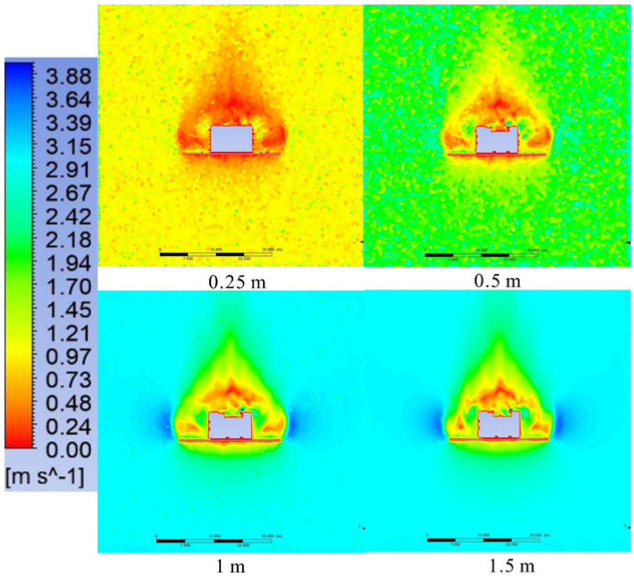

Fig. 7. Top plane view of the wind pattern at different elevations where the fence without holes is located 0.5 m away from house wall (façade)

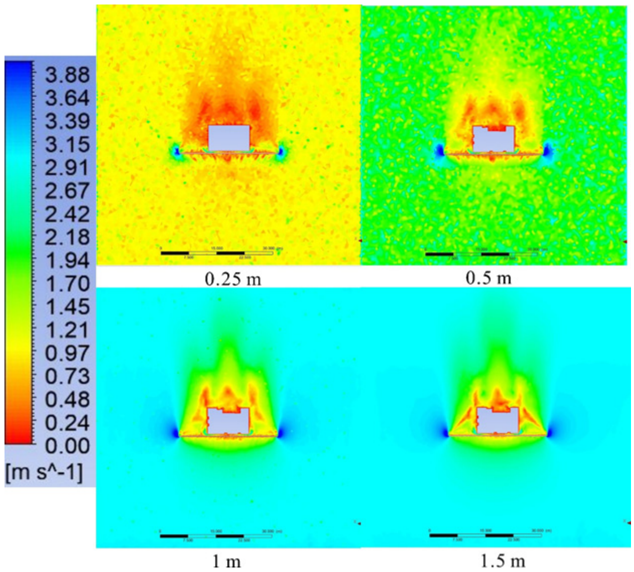

Fig. 8. Top plane view of the wind pattern at different elevations where the fence with holes is located 0.5 m away from house wall (façade)

Fig. 8. gives the top plane view of wind pattern at different elevations subject to the configuration as given in Fig. 6. when the fence is porous with 3 cm holes present across its complete geometry.

A noticeable change in the wind flow pattern can be seen when compared to the previous case as shown in Fig. 7. This is predominantly due to the introduction of holes in the fence geometry. The wind can pass through the holes and escape towards the side edges of the house. This also results in a higher velocity near the edges of the house as compared to the case given in Fig. 7. The velocity is very low in the middle portion due to the

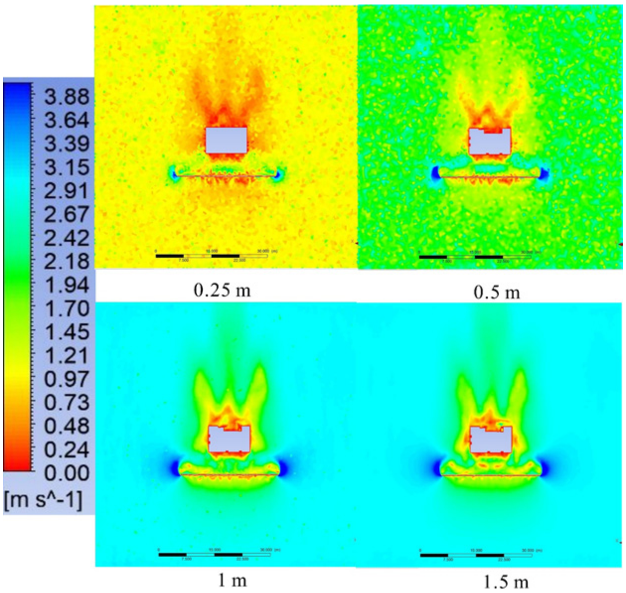

Fig. 9. Top plane view of the wind pattern at different elevations where the fence without holes is located 6m away from house wall (façade)

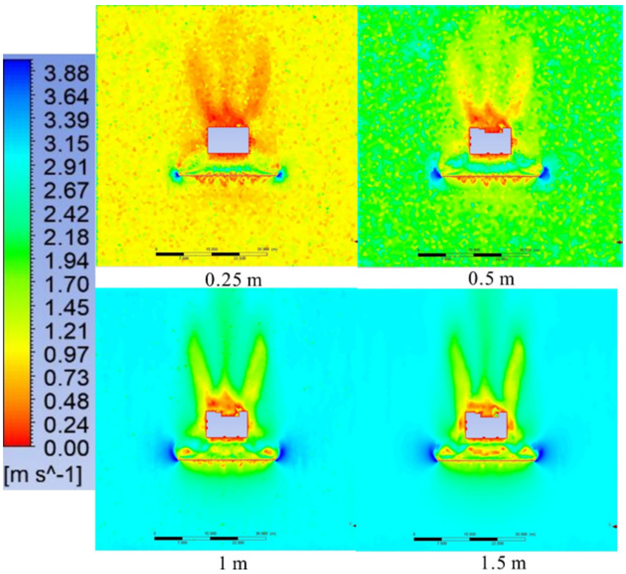

Fig. 10. Top plane view of the wind pattern at different elevations where the fence with holes is located 6m away from house wall (façade)

boundary layer effect and little room available for the incoming wind streams to escape.

Fig. 9. gives the top plane view of the wind pattern at different elevations for the case when a nonporous fence (solid fence without holes) is located 6m away from the house wall (façade). As the distance between the façade and fence becomes greater, the prevailing wind pattern is mostly unaffected by the reduction in wind speed due to the boundary layer growth as observed in the previous cases. The wind can freely flow over the fence and around the edges of houses. The reduction in wind speed due to the presence of the fence is also decreased as can be seen in the

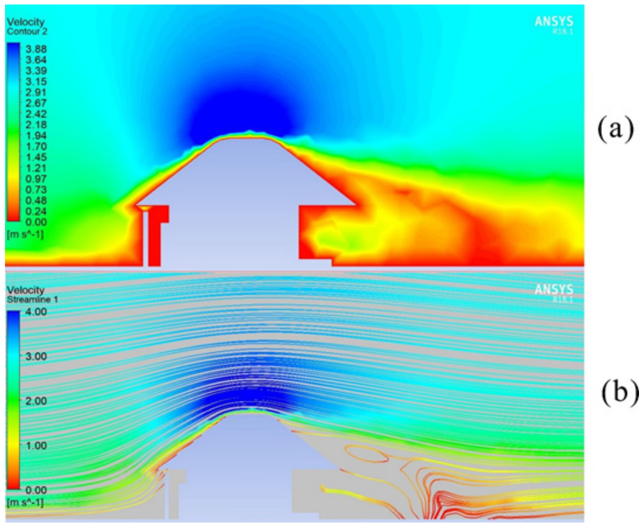

Fig. 11. Side plane view of the wind pattern for the fence without holes located 0.5 m away from wall; (a) velocity contour, (b) velocity streamlines

overall wind flow pattern.

Fig. 10. gives the top plane view of the wind pattern at different elevations for the case when the fence with holes is located 6m away from house wall (façade). The wind flow pattern is quite similar to the case observed in Fig. 9. At such a large distance between the fence and the house wall, the effect of boundary layer growth between the fence and the façade is significantly reduced. The major difference between these two cases, as observed in Figs. 9. and 10., was in the formation of vortex after the fence. This difference in the formation of vortex arose from the presence of holes affecting the boundary layer thickness.

Side plane view results for all the cases discussed above were also presented to provide better understanding of wind flow pattern as it develops in and around the fence and the house. Both the velocity contours and velocity streamlines are provided to get a better understanding of the interaction of wind with the model geometries.

Fig. 11. shows the side plane view of the wind flow pattern for the case when the fence is solid and the distance between the fence and the façade is only 0.5m. Due to the boundary layer growth and small distance between the two surfaces (fence and façade), there seems to be little room for the wind to flow through. The streamlines image also show that no wind streams are able to enter in such a narrow space. Hence, the velocity after the fence is almost zero. There is sharp increase in the wind velocity over the roof where it increases up to 4m/s. Behind the house, the velocity drops to 0m/s due to the formation of a wake region and the boundary layer effect in contact with solid surfaces (walls of the house, ground level). As the distance from the solid surfaces increases, the wind velocity increases up to 2m/s.

Fig. 12. presents the side plane view of the wind flow pattern

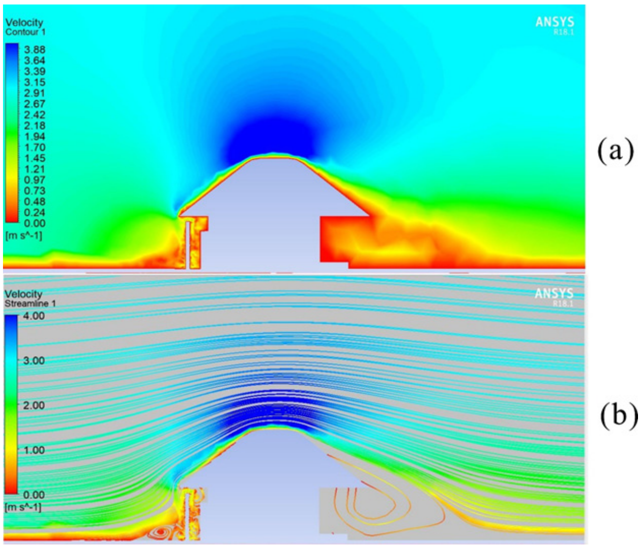

Fig. 12. Side plane view of the wind pattern for the fence with holes located 0.5 m away from house wall (façade); (a) velocity contour, (b) velocity streamlines

for case when the fence is porous located 0.5m away from the façade of the house. The velocity of air is higher after passing the fence when compared to the case considered in Fig. 11. This is due to the introduction of holes. The introduction of holes provides alternative paths for the wind to streamline through the fence geometry. As a result the effect of boundary layer and wake region is reduced considerably.

The velocity gradually increases from 0m/s in the close vicinity to 2m/s at a distance behind the house geometry. The streamlines image shows the velocity streamlines that are able to pass through the holes and enter the region between fence and the façade.

Fig. 13. gives the side plane view of the wind flow pattern for the case when the fence is solid (nonporous) and at a 6m from façade of the house. The distance between the fence and façade is much greater than the boundary layer thickness. Therefore, the wind streams can move freely over and across the fence where low-speed winds are observed only close to the edges of fence and façade.

There is a sharp increase in wind speeds over the edges of the fence. The wind streamlines deem to follow two pathways. First, the wind flows over the fence and then towards the roof experiencing an increase in its velocity. Second, it flows over the fence and towards the ground and the façade (of the building). Due to the difference in velocities between these two major streamlines, a vortex is created in the region between the fence and the façade. The wind speed appeared to be higher in this region when compared to the previous cases.

Fig. 14. gives the side plane view of the wind pattern for case when the fence has holes (porous) and at 6m from the façade of the house. The wind flow pattern is similar to the case in Fig. 13.,

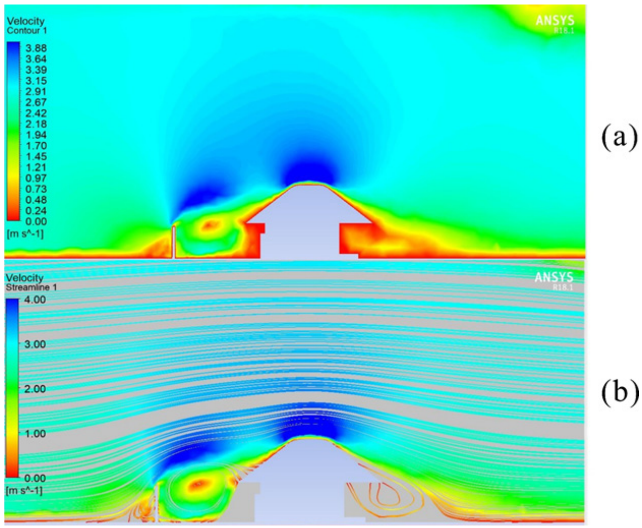

Fig. 13. Side plane view of the wind pattern when the fence without holes is located 6 m from house wall (façade); (a) velocity contour, (b) velocity streamlines

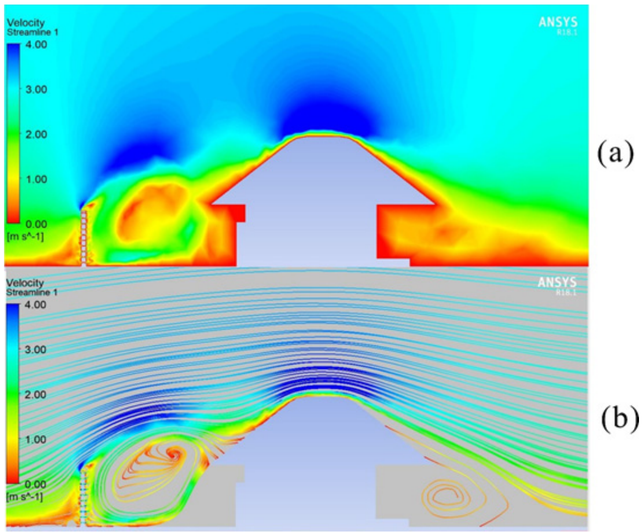

Fig. 14. Side plane view of the wind pattern when the porous fence with holes is located 6 m away from house wall (façade); (a) velocity contour, (b) velocity streamlines

in the manner that wind flows over the fence and roof of the house.

However, due to the inclusion of holes in fence geometry, the region between the fence and façade is different. Along with the two pathways as described in conjunction with Fig. 13., the wind flows through the holes and towards the façade (of the house). Due to this reason, the vortex generated is slightly different when compared to the case that without holes in the fence.

The wind streams tend to flow across a path of least resistance. Therefore, even with holes in the fence geometry, the wind stream will follow a path of higher velocity as it goes over the fence and house geometry. The velocity after the fence is affected by the distance between the fence and house wall. In case of fence without any holes, the wind speed is almost zero in case of 0.5 m

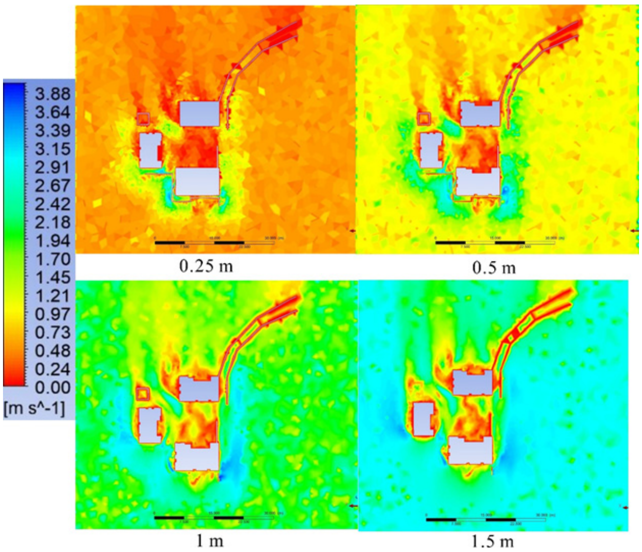

Fig. 15. Top plane view of wind pattern for the three-house geometry with porous fence of 0.5m in height

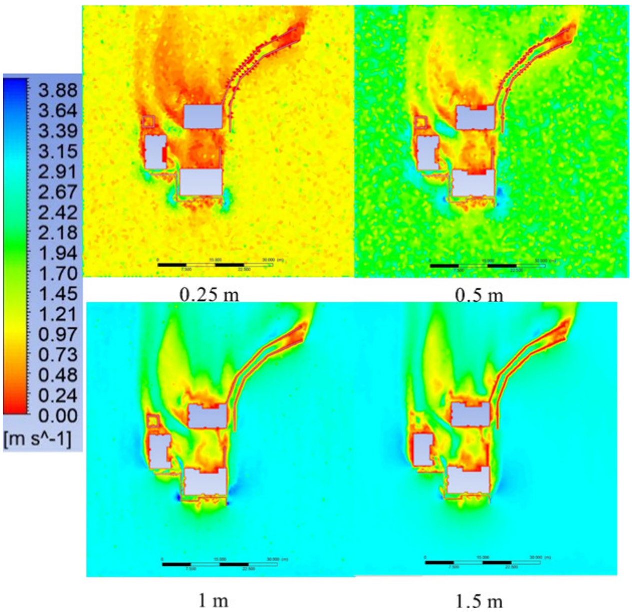

Fig. 16. Top plane view of wind pattern for three-house geometry with a 1.5m high fence with holes and height of 1.5m

distance between the fence and the wall. As there is no room for wind to flow in this region, i.e. between the fence and the wall of the house structure, wind mostly flows upwards and pass through the sides of the house. When the holes are introduced in the fence geometry, it provides an alternate pathway for the wind to go through. This results in a relatively higher wind speed as compared to without any holes at the same distance from the house. For the case of 6m, the velocity between the fence and the wall increases up to 2m/s. This is because the boundary layer growth has lesser effect as the wind blows over the fence and its velocity field develops in this region. Another effect that is prominent is the sharp increase in velocity over the edges of the fence and the roof of the house. In such cases, the wind speed increases up to 4m/s. The wind speed is especially higher near the side edges of the house. This is because the wind coming through the holes can easily escape along the side edges of house.

3.2 "Yang Geum-seok" residence model (full scale model)

Fig. 15. gives the top plane view of the wind pattern for the three-house geometry. The distance between the north facing fence and the façade of the Angeori building is 0.5m and the height of the fence is 0.5m as well. The fence is porous with holes of 0.03m diameter across its geometry. The wind can follow two passageways due to the introduction of holes; it can go over the holes and pass through the fence. This results in a relatively higher velocity region between the fence and house wall. It is noticeably higher towards the left edge of the Angeori building where it can go over the fence and pass through the region between the Angeori and Mogeori buildings.

Fig. 16. gives the side plane view of the wind pattern for the three-house geometry with a fence with holes whose height is 1.5 m. The north facing fence is porous with 0.03m diameter holes across all its geometry and its height is 1.5m. The inclusion of holes facilitates the flow of wind by providing an additional passage. When compared with Fig. 15., the effect of fence height becomes more noticeable as the wind blows closer to the ground.

4. Conclusions

A numerical experiment has been carried out to explore the effect of porous fences in vernacular architecture in Jeju, comprised of three residential buildings each with a thatched roof. Two numerical models (a simple one fence one building model followed by a full scale actual model) were developed to study the effect of a porous fence and building elements as the wind blows in and around them. Results indicate the dominant effect of holes in the fence as well as the location of a fence away from the building in the formation of wind streams interacting with building elements. Especially, the latter provided a crucial reason why a stone fence was built close to a building structure as witnessed in the case of a typical vernacular architecture in Jeju, the "Yang Geum-seok" residence. The various results obtained here could be further extended in designing a fence with porosity in conjunction with building elements in windy areas.

Acknowledgement

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education (Grant No. 2016R1D1A1B04934265).

Reference

[1] J.J. Lee, G.Y. Jeon, Architectural and exterior material features according to the climatic difference in Jeju houses, Korea: Journal of the Korean Society of Living Environmental System, 21(1), 2014, pp.42-50.
[2] J.J. Lee, G.Y. Jeon, Research on the effect of stonewall on airflow environment of a country house in Jeju: Proceedings of the 2012 AIK-RA conference, 8(1), 2012, pp. 595-598.
[3] C.H. Lee, C.K. Park, A Study on the environmentally-friendly characteristic of traditional houses in Jeju, Korea: Journal of the Korean Institute of Rural Architecture, 16(2), 2014, pp.35-44.
[4] Y.C. Jeong, H.S. Lee, A Study on the formation and characteristic of the domestic vernacular houses in Cheju island, Korea: Journal of the Architectural Institute of Korea, 7(3), 1991, pp.113-122.
[5] H.Y. Kwak, J.W. Yoo, K. Onomichi, A Comparative study on architectural characteristics of vernacular houses in Jeju and Okinawa island - As environment factors of the wind and rain, Korea: Journal of the Architectural Institute of Korea Planning & Design, 23(5), 2007, pp.11-20.
[6] C.J. Kim, J.H. Yoo, Study of vernacular design characteristics of Korean traditional village, Korea: Journal of the Korean Institute of Spatial Design, 8(3), 2013. pp.93-102.
[7] G. Chen, W. Wang, C. Sun, J. Li, 3D numerical simulation of wind flow behind a new porous fence, Podwer Technology, 230, 2012, pp. 118–126.
[8] G. Xin, N. Huang, J. Zhang, H. Dun, Investigations into the design of sand control fence for Gobi buildings, Aeolian Research, 49, 2021, p. 100662.
[9] W.N. W Yahya, S.S. Zaini, T.A. Majid, M.A. Ismail, S.N. C Deraman, J. Abdullah, Numerical investigation on the effects of wind direction to the air flow characteristics surrounding an isolated rural house, IOP Conference Series Earth Environment Science, 244, 2019, p.012031.
[10] J.L. Santiago, F. Martín, A. Cuerva, N. Bezdenejnykh, A. Sanz-Andrés, Experimental and numerical study of wind flow behind windbreaks, Atmospheric Environment, 41, 2007, pp.6406–6420.
[11] K. Ko, K. Kim, J. Huh, Variations of wind speed in time on Jeju Island, Korea, Energy, 35, 2010, pp.3381–3387.