Optimization designs of artificial facilities in deserts based on computational simulation Postprint

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Abstract

Sediment transport of sand particles by wind is one of the main processes leading to desertification in arid regions, which severely impairs the ability of mankind to produce and live by drifting sand into settlements. Optimization designs of artificial facilities have lately attracted extensive interest for human settlement systems in deserts because of their acceptable protection effect, convenience of implementation, and low material cost. However, the complexity of a settlement system poses challenges concerning finding suitable materials, artificial facilities, and optimization designs for sand deposition protection. In an effort to overcome these challenges, we propose a settlement system built with brick, solar panel, and building arrays to meet the basic needs of human settlements in arid regions while preventing wind-sand disasters. The wind flow and movement characteristics of sand particles in the brick, panel, and building arrays were calculated using computational fluid dynamics and discrete phase model. The performance of three types of arrays in wind-sand flow in terms of decreasing the wind velocity and sand-particle invasion distance was evaluated. The results show that the wind velocity near the surface and the sand invasion distance were significantly decreased in the space between the brick arrays through properly selected vertical size and interspaces, indicating that the brick arrays have an impressive sand fixing and blocking performance; their effective protection distance was 3–4 m. The building arrays increased the near-surface wind velocity among buildings, resulting in less deposition of sand particles. The solar panel arrays were similar to the building arrays in most cases, but the deposition of sand particles on solar panels exerted a negative effect on energy utilization efficiency. Therefore, taking the optimal configuration of the settlement system into consideration, this study concludes that (1) brick arrays, which were proven effective in preventing sand particles, must be arranged in an upwind area; (2) solar panel arrays could accelerate the wind flow, so they are best to be arranged at the place where sand particles deposited easily; and (3) building arrays present a better arrangement in downwind areas.

Full Text

Abstract

Sediment transport of sand particles by wind is one of the main processes leading to desertification in arid regions, which severely impairs human production and living conditions by drifting sand into settlements. Optimization designs of artificial facilities have lately attracted extensive interest for human settlement systems in deserts because of their acceptable protection effect, convenience of implementation, and low material cost. However, the complexity of settlement systems poses challenges concerning the selection of suitable materials, artificial facilities, and optimization designs for sand deposition protection. To overcome these challenges, we propose a settlement system built with brick, solar panel, and building arrays to meet the basic needs of human settlements in arid regions while preventing wind-sand disasters. The wind flow and movement characteristics of sand particles in the brick, panel, and building arrays were calculated using computational fluid dynamics and the discrete phase model. The performance of the three types of arrays in wind-sand flow in terms of decreasing wind velocity and sand-particle invasion distance was evaluated. The results show that wind velocity near the surface and sand invasion distance were significantly decreased in the space between the brick arrays through properly selected vertical size and interspaces, indicating that brick arrays have impressive sand-fixing and blocking performance with an effective protection distance of 3–4 m. Building arrays increased near-surface wind velocity among buildings, resulting in less deposition of sand particles. Solar panel arrays were similar to building arrays in most cases, but the deposition of sand particles on solar panels exerted a negative effect on energy utilization efficiency. Therefore, considering the optimal configuration of the settlement system, this study concludes that (1) brick arrays, which proved effective in preventing sand particles, must be arranged in upwind areas; (2) solar panel arrays could accelerate wind flow, so they are best arranged where sand particles deposit easily; and (3) building arrays are better suited for downwind areas.

Keywords: desert city; sand deposition; optimization; wind flow; sand movement

1 Introduction

Desertification is one of the most serious environmental problems worldwide, intensifying sediment transportation by wind and leading to desert expansion [**?**, **?**]. Desert areas account for 20% of the Earth’ s land area and are continuously expanding rapidly. Approximately 0.75×10^9 people currently live in arid regions worldwide, and growing population density adds pressure to the ecological environment [**?**]. Specifically, in Xinjiang Uygur Autonomous Region of

China, new countryside construction was carried out in recent years to improve human life quality, making it desirable to investigate wind flow and sediment transportation in human settlements [?].

The number of theoretical and experimental studies on novel tiled barriers for sand encroachment protection has notably increased, including low-height sand fences [?, ?, ?, ?], straw checkerboard barriers [?, ?, ?, ?, ?], clay barriers [?], plastic checkerboard barriers [?, ?], and brick arrays [?]. Tiled barriers are usually low in height because 90% of sand grains encountering aerodynamic entrainment are located within 10–50 cm above the ground [?, ?, ?, ?]. Straw checkerboard barriers are typical tiled barriers widely used to prevent sand disasters along railways in China.

Studies of sand transport and deposition processes in straw checkerboard barriers have been promoted by simplified theoretical analysis [?] and air-particle two-phase flow simulation [?, ?]. As the latest development, Xu et al. [?] simulated wind-sand flow around straw checkerboard barriers using large eddy simulation and the particle-trajectory method to explore turbulent flow characteristics, sand particle transport, and deposition processes. They found that huge single streamwise vortices filled the internal space of straw checkerboard barrier cells, with double spanwise vortices located behind the cells.

Considering the important role of porosity in sand fence effectiveness [?], Zhang et al. [?] studied the shelter effect of a porous fence on wind-sand flow using a high-speed digital camera and particle-tracking velocimetry. These studies found that transport rate and kinetic energy of sand can be reduced by more than 80% and 90%, respectively. Inspired by this, Chen et al. [?] experimentally and numerically studied the shelter effect of porous sand fences, finding that a deflector-porous fence with 30% porosity, 150 mm height, and 150 mm distance between the fence and prism model was most effective in controlling dust emission. Combining advantages of these two main tiled barriers, brick arrays made of clay have attracted considerable interest because of their acceptable effect, easy implementation, environmental friendliness, and low cost [?]. However, despite these advantages, development of brick arrays is mainly retarded by a lack of thorough analysis of sand particle transport and deposition processes.

Artificial facilities such as buildings and solar panels significantly influence atmospheric boundary-layer flow, but most simulations of flow fields around obstacles only model isolated structures rather than groups of obstacles [?]. For example, many scholars have calculated flow fields around an isolated building [?, ?, ?] and around two interactive buildings [?, ?] based on the Reynolds-averaged Navier-Stokes (RANS) method. Hunter et al. [?] calculated three-dimensional (3-D) characteristics of flow fields within urban canyons based on turbulence models. However, the shortage of studies on sand-particle movement characteristics among groups of buildings limits optimization design effectiveness.

In this study, we propose a human settlement system referring to a previous study on desert cities [?]. The system includes brick, solar panel, and building arrays to meet basic needs for wind-sand disaster prevention, electric power, and human settlements, with all elements working together to prevent sand encroachment. To obtain the best arrangement of these facilities, we calculated 3-D turbulent wind flow and sand-particle movement characteristics around the brick, solar panel, and building arrays using the computational fluid dynamics (CFD)-discrete phase model (DPM) method. The effects of the three types of arrays in wind-sand flow on decreasing mean air velocity and sand particle invasion distance were evaluated.

2.1 Fluid-phase governing equations

2.1.1 3-D Reynolds-averaged Navier-Stokes (RANS) equations

This study assumes that fluid flow satisfies the continuity equation and 3-D RANS momentum equation, with a neutral atmospheric boundary layer existing in the flow field. Heat and mass transfer processes are not considered. The model is simplified by assuming a non-slip boundary condition at the ground and incompressible fluid flow with constant density of =1.225 kg/m^3 and viscosity of =0.01789 g/(m · s).

The continuity equation is expressed as:

$$\frac{\partial u_i}{\partial x_i} = 0, \tag{1}$$

where u_i and x_i denote fluid velocity (m/s) and microelement position from the origin (m) in the ith direction, respectively.

The momentum equation is listed as follows [**?**]:

$$\rho \frac{\partial u_i}{\partial t} + \rho u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j} - \rho \overline{u_i' u_j'}\right) + F_{s,i}, \tag{2}$$

where the Reynolds stress term is:

$$-\rho \overline{u_i' u_j'} = \mu_t \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\rho k \delta_{ij}, \tag{3}$$

and the source term from sand particles is:

$$F_{s,i} = \frac{1}{V_{\text{cell}}} \sum_{n=1}^{N} F_{D,i}^{n}, \tag{4}$$

where A is the Reynolds stress caused by turbulence (Pa); p is static pressure (Pa); F_s is reactive force from sand particles (N); V_{cell} is volume of a fluid grid cell (m^3); n is number of sand particles in the grid cell; and F_{Di} is drag force acting on a single sand particle by airflow (N).

2.1.2 Turbulence model

Turbulence flow was simulated using the renormalization group (RNG) k- turbulence model, which is effective at predicting complex flow behavior. The complete formulation of the RNG k- turbulence model is given as follows [**?**]:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left(\alpha_k\mu_{\text{eff}}\frac{\partial k}{\partial x_j}\right)+G_k+G_b-\rho\varepsilon-Y_M+S_k, \quad (5)$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left(\alpha_\varepsilon\mu_{\text{eff}}\frac{\partial \varepsilon}{\partial x_j}\right)+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}-R_\varepsilon+S_\varepsilon, \quad (6)$$

$$\mu_{\text{eff}}=\mu+\mu_t, \quad (7)$$

$$\mu_t=\rho C_\mu\frac{k^2}{\varepsilon}, \quad (8)$$

$$R_\varepsilon=\frac{C_\mu\rho\eta^3(1-\eta/\eta_0)}{1+\beta\eta^3}\frac{\varepsilon^2}{k}, \quad (9)$$

$$\eta=\frac{Sk}{\varepsilon}, \quad (10)$$

$$S=\sqrt{2S_{ij}S_{ij}}, \quad (11)$$

$$S_{ij}=\frac{1}{2}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right), \quad (12)$$

where k is kinetic energy ($m^{2/s}2$); is kinetic-energy dissipation rate ($m^{2/s}3$); σ_k and σ *are Prandtl numbers for kinetic energy and dissipation rate, respectively;* S{ij} is shearing-rate tensor (Pa); G_k presents generation of turbulence kinetic energy due to mean velocity gradients (kg/(m·s^3)); C**{2 } are coefficients related to air density;* E{ij} is mean strain rate; is coefficient of E_{ij}; and _t is turbulence viscosity. Default coefficient values in the transport equations for k and are: C_ =0.085; C_{1 }=1.42; C_{2 }=1.68; σ_k=0.72; σ_ =1.0; β=0.012; _0=4.38.

2.2 Sand-particle kinetic equation

Forces applied to a single sand particle are assumed to be gravity (F__g) and fluid drag force (F__D), expressed as follows [?]:

$$\mathbf{F}_g = \frac{\pi D^3}{6}\rho_p \mathbf{g}, \tag{13}$$

$$\mathbf{F}_D = \frac{\pi D^2}{4} C_D \frac{1}{2}\rho |\mathbf{V}_r| \mathbf{V}_r, \tag{14}$$

$$C_D = \begin{cases} 0.63 + \frac{4.8}{\sqrt{Re}} & \text{if } Re < 1000 \\ 0.44 & \text{if } Re \geq 1000 \end{cases}, \tag{15}$$

$$Re = \frac{\rho D |\mathbf{V}_r|}{\mu}, \tag{16}$$

$$\mathbf{V}_r = (u - u_D, v - v_D, w - w_D), \tag{17}$$

where __p is particle density (kg/m^3); D is particle diameter (m); g is gravitational acceleration (9.8 m/s^2); C__D is fluid drag coefficient; Re is Reynolds number; and V__r is relative velocity (m/s). In addition, u, v, and w are three velocity components of air in x, y, and z directions, respectively; u__D, v__D, and w__D are three velocity components (m/s) of sand particle in x, y, and z directions, respectively.

The kinetic equation for sand particles is [?]:

$$m_p \frac{d\mathbf{U}_D}{dt} = \mathbf{F}_g + \mathbf{F}_D, \tag{18}$$

where m__p and U__D are mass (kg) and velocity (m/s) of sand particle, respectively.

2.3 Numerical simulation method

Simulations were performed using the commercially available software package FLUENT (ANSYS, USA). In the solution procedure, nonlinear partial differential equations of the model were discretized using the finite volume method, and the segregated solution algorithm was selected. Pressure and velocity fields were decoupled using the semi-implicit method for pressure-linked equations (SIMPLE). The discrete phase model was used to solve sand-particle movements. Fluid-phase governing equations and sand-particle kinetic equations were also decoupled in this study.

2.4 Computational domain and boundary conditions

A system including brick, solar panel, and building arrays to meet basic needs for wind-sand disaster prevention, electric power, and human settlements has been proposed in this work (Fig. 1 [Figure 1: see original paper]). Brick arrays are located outside the desert city to prevent wind-sand disasters; solar panel arrays, commercial districts, industrial districts, and lakes are set on the edge of the desert city to provide limited protection; building arrays form the core of the desert city to meet basic human settlement needs. All arrays are single-layer in the vertical direction.

Figure 2 [Figure 2: see original paper] presents the schematic illustration of computational domains for the 3-D model based on the assumption that wind field velocity at the inlet follows the logarithmic velocity profile:

$$u(z) = \frac{u_*}{k} \ln\left(\frac{z}{z_0}\right), \tag{19}$$

where z is fluid microelement height (m); z_0 is flat surface roughness (m); k is von Karman constant (0.41); and u_* is friction velocity (m/s).

Pressure at the outlet was specified as reference pressure. Symmetry boundary conditions were used for lateral computational domains, and non-slip wall boundary conditions were applied to the ground and surfaces of brick, solar panel, and building arrays (Fig. 2). Convergence criterion for the RNG k-turbulence model was residuals less than 1$×$10^-6.

In simulations, sand particles were placed 1 m before arrays as a line source at a density of 5$×$10^4 per meter. Sand-particle diameter was 0.2 mm. All sand particles had upward velocities ranging from 0.067–1.500 m/s as initial conditions, obeying a probability density function depending on velocity as follows [**?**]:

$$f(V_{\mathrm{up}}) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(V_{\mathrm{up}} - \mu)^2}{2\sigma^2}\right). \tag{20}$$

2.5 Grid system

To achieve satisfactory trade-off between computational cost and need for capturing significant flow field variations, a hybrid grid system was used to mesh the computational domain. The domain was split into two zones: the upper zone was meshed with hexahedron grids, and the lower zone with tetrahedron grids. Further, the inflation method was applied to boundary cells to correctly reflect physical phenomena at boundaries. Computational grids maintained a warping factor below 0.25, with maximum aspect ratio less than 40. Overall, grids comprised approximately 2.0$×$10^6 individual cells.

2.6 Numerical validation

The numerical method was tested in four cases of wind flowing over a rough block surface. Height, breadth, and separation distance of blocks are denoted as h, l, and d, respectively (m). Roughness concentration λ, defined as ratio of frontal area to floor area per block, was calculated as:

$$\lambda = \frac{hl}{d^2}. \tag{21}$$

Roughness length z_h was computed from wind profiles. Figure 3 [Figure 3: see original paper] shows that the calculated curve of roughness length z_h normalized by height h versus roughness concentration λ is in good agreement with the experimental curve reported by Raupach et al. [**?**].

3 Results and discussion

In simulations, the longitudinal direction aligned with the streamwise direction, and the horizontal direction was transverse. To evaluate each array type' s performance in fixing and blocking sand particles, we defined the average velocity in the plane 0.02 m above ground as mean sand particle velocity [**?**], and the longest particle movement distance within arrays as invasion distance. All simulated cases are listed in Table 1 , with parameters including element sizes, separation distances among brick, solar panel, and building arrays, and panel laying angle. This section also discusses the influence of friction velocity on wind flow and sand particle invasion distance.

3.1 Brick arrays

Figure 4 [Figure 4: see original paper] shows flow velocity field and sand particle movement in brick arrays. As shown in Figure 4a, a series of eddies emerged within brick arrays, and airflow velocity was significantly reduced compared to air above the bricks. In comparison, straw checkerboard barriers consist of continuous lattice structures that force airflow over the sides and result in progressively smaller eddies in the streamwise direction [**?**, **?**], while airflow can bypass bricks through spaces between individual bricks. Therefore, eddy sizes were smaller and near-surface wind flow at different positions was more uniform than over straw checkerboard barriers. Figure 4b presents sand particle movement characteristics around brick arrays. These particles moved forward in interspaces between bricks, and the number of airborne sand particles clearly decreased, indicating more deposition on the surface. This movement pattern kept sand particles near the surface and rapidly weakened forward momentum, which was obviously more beneficial for sand encroachment protection. As a comparison, some sand particles may jump over 20 cm when colliding with straw checkerboard barrier sides, significantly increasing wind-driven sand transport distances.

Mean velocity increased significantly when widening horizontal space between bricks (Fig. 5a [Figure 5: see original paper]). When longitudinal space reached 0.4 m, mean velocity decreased to a constant value then increased slightly with further horizontal space increase (Fig. 5a). This occurs because when air flows through bricks with suitable longitudinal space, a series of eddies emerges within brick arrays and consumes substantial airflow energy near the surface. Mean velocity increased with longitudinal size and decreased with horizontal or vertical size increase (Fig. 5b). Clearly, increasing vertical size is very effective for reducing mean velocity when vertical size is less than 0.25 m. Thus, optimizing brick space and size may most efficiently decrease airflow mean velocity.

Furthermore, mean velocity increased linearly with friction velocity increase (Fig. 5c). Invasion distance variation is shown in Figure 6a [Figure 6: see original paper]. Notably, invasion distance first decreased then increased rapidly as longitudinal space increased. Compared with Figure 5a, both lines reached their lowest point when longitudinal space was 0.4 m. This can be explained by the fact that most airflow power was used to form eddies between bricks, leaving minimal power to push sand particles forward in this case. Figure 6b shows more complicated invasion distance changes with brick size variation. Invasion distance significantly increased then decreased with vertical size increase. This may be explained by the fact that more airflow entered interspaces between bricks initially, accelerating wind flow. As vertical size increased, brick form drag was significantly enhanced, slowing airflow velocity near the surface. Moreover, brick arrays were better at blocking sand particles when friction velocity was low (Fig. 6c). Evidently, appropriate adjustment of brick spaces and sizes can significantly decrease invasion distance by typically 3–4 m, which is slightly longer than that of straw checkerboard barriers [**?**, **?**, **?**, **?**].

3.2 Solar panel arrays

Another series of simulations evaluated sand-fixing and blocking performance of solar panel arrays. As shown in Figure 7a [Figure 7: see original paper], a series of eddies emerged within solar panel arrays, and airflow velocity was significantly reduced in the same regions as brick arrays. Figure 7b presents sand particle movement characteristics around solar panel arrays. Most sand particles rapidly passed through interspaces between solar panel arrays, suggesting that solar panel arrays are less effective for blocking sand than brick arrays. In contrast to brick arrays, some sand particles could move above solar panels due to the laying angle, with a few particles depositing on them. This is a typical phenomenon in solar panel applications that negatively affects energy generation [**?**]. Compared with most previous studies focusing on pollutant effects [**?**, **?**, **?**], our simulation results reproduced sand particle deposition processes on solar panels, which will be helpful for improving energy utilization efficiency.

Figure 8 [Figure 8: see original paper] illustrates that changing horizontal space, longitudinal space, or solar panel sizes had little effect on reducing mean velocity unless horizontal space was very small. In other words, solar panel arrays exhibited best sand-fixing and blocking performance when panels were close to a wall row. Figure 8c shows that mean velocity decreased when increasing the angle between solar panels and ground, and Figure 8d demonstrates that mean velocity increased linearly with friction velocity increase. Generally, mean velocity increased in most cases because solar panel arrays can increase airflow entering interspaces between panels unless horizontal space is very small, and can remove sand particles by enhancing airflow in specific configurations. Thus, solar panel arrays played a flexible role in either blocking incoming sand particles or removing sand accumulation according to specific conditions.

3.3 Building arrays

Figure 9 [Figure 9: see original paper] presents flow velocity field and sand particle movement in building arrays. As shown in Figure 9a, a series of eddies emerged within building arrays, and airflow velocity was significantly reduced in the same regions as brick and solar panel arrays. The longitudinal space was replete with a large eddy when approximately equal to brick height. This has also been observed by Kanda et al. [?] in laboratory large-eddy simulation results, which confirmed isolated large eddies in canyon flow regimes. Building spacing was significantly larger than brick spacing in the described situation, and eddies had no chance to reduce airflow power near the surface between arrays.

Figure 9b shows that most sand particles rapidly passed through interspaces between building arrays, with only a few depositing in front of buildings. This coincides with transport and deposition characteristics of particulate pollutants in urban street canyons summarized by Yazid et al. [?]. Our results suggest that blown sand hazards have little effect on building arrays on flat surfaces.

Figure 10 [Figure 10: see original paper] illustrates that changing horizontal space, longitudinal space, or building sizes had little effect on reducing mean velocity in most cases. Similar to solar panel arrays, Figure 10a shows that mean velocity was significantly reduced when horizontal space was small, but remained too high to prevent sand particle movement. According to Figure 10b, canyon effect was enhanced due to increased vertical size and airflow entering interspaces between buildings, so mean velocity evidently increased with vertical size. Figure 10c shows that mean velocity increased linearly with friction velocity. Thus, there was no risk of burial damage from sand flow when building arrays were arranged in appropriate configurations.

3.4 Distribution of sand flux

Variations in sand flux distribution in the streamwise direction within brick arrays are shown in Figure 11 [Figure 11: see original paper] to investigate array influence on wind-sand flow development. Note that changes in horizontal brick space and horizontal size significantly influenced sand-flux rate at the inlet due to complex boundary and flow field conditions [?], with influence decreasing as sand flow entered brick arrays. This occurs because entering space for sand into brick arrays became smaller when horizontal size increased and horizontal space decreased, resisting more sand particles outside. However, wind flow in the streamwise direction was hardly affected in these situations, and sand fluxes and invasion distances were almost identical inside brick arrays. Figure 11a shows that although increasing longitudinal space had slight impact on sand-flux rate at brick array inlets, it increased wind-flow structure in the streamwise direction inside brick arrays, thereby enhancing sand-flux rates and invasion distances by providing more energy to sand particles.

Figure 11b illustrates that sand flux peaked when vertical size was approximately 0.2 m, indicating this vertical size may strengthen wind-flow structure, while 0.1 m was a more proper vertical size for tiled barriers in sand encroachment protection [**?**, **?**]. Figure 11c suggests that brick arrays performed better when sand-flux rate was reduced at low friction velocity. Due to minimal effect on blocking sand particles in most situations, sand flux distributions in solar panels and building arrays were not the primary focus of this study.

3.5 Configuration considerations

Generally, most settlements are composed of brick, solar panel, and building arrays to meet basic human needs, with few other human facilities affecting wind flow and sand movement. In this case, the three array types considered in this study should be the main focus of configuration considerations for human settlements.

The above results suggest that brick arrays have the most significant effect on reducing mean airflow velocity and sand particle invasion distance, demonstrating good sand-fixing and blocking performance. Both solar panel and building arrays, however, can increase mean velocity in most cases and block deposition of most sand particles. Exceptionally, solar panel arrays have significant sand-fixing and blocking effects when horizontal space is small. Consequently, brick arrays must be arranged in upwind areas to stop sand-particle movement and fix them on the ground. Solar panel arrays are supposed to accelerate wind flow where sand particles deposit easily, and building arrays should be arranged in downwind areas.

4 Conclusions

Invasion distance and mean velocity significantly decreased in spaces between brick arrays with properly selected vertical size and interspace, indicating that brick arrays have remarkable sand-fixing and blocking performance with an effective protection distance of 3–4 m.

Regarding solar panel array simulation results, mean velocity increased in most cases unless horizontal space was very small, and sand particles could be removed by enhancing airflow in specific configurations. Sand particle deposition on solar panels was simulated, which will benefit future studies on improving energy utilization efficiency.

Large building spaces hindered reduction of airflow power near the surface between arrays, resulting in most sand particles rapidly passing through interspaces between building arrays with only a few depositing in front of buildings. These results suggest that blown sand hazards have little effect on building arrays on flat surfaces.

Hence, considering optimal settlement system configuration, this study concludes that: (1) brick arrays must be arranged in upwind areas; (2) solar panel arrays could accelerate wind flow, so they are best arranged where sand particles deposit easily; and (3) building arrays must be arranged in downwind areas.

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Note: Figure translations are in progress. See original paper for figures.