International Journal of Architecture and Urban Development
Vol.6, No.2, Spring 2016

Modeling Airflow in Urban Form against Sand Accumulation (case Study: Saltation in the Town of Timimoun in Southern Algeria)

[1*]Djamel Mestoul, [2]Rafik Bensalem, [3]Luc Adolphe

[1]Ph.D. Candidate, Laboratoire Architecture et environnement (LAE), Ecole Polytechnique d'Architecture et d'Urbanisme, EPAU, Alger-Algérie.
[2]Professor, Ecole Polytechnique d'Architecture et d'Urbanisme, EPAU, Alger-Algérie.
[3]Professor, Ecole Nationale d'Architecture de Toulouse, Toulouse, France.

Recieved 10.01.2015; Accepted 03.14.2016

ABSTRACT: In our present research, we focus on the modeling of airflow related to natural disasters, such as sand accumulation, with urban form studies. The objective is to find which urban form can promote sand passing and reduce as much as possible stagnation of sand in the building area (streets, alleys, etc.). The urban form design will be discussed through the simulation of airflow by using Computational Fluid Dynamics (CFD). In terms of simulation, we simulated the airflow behavior, which is responsible of sand stagnation in some specific configurations. A flat ground was chosen with a first configuration, which was varied to test each time a current airflow behavior in this configuration. This modeling is made possible following an appropriate turbulence model. In this study, a correlation was made between urban wind speed and morphological parameters such as aspect ratio, building geometry and building density. According to our theoretical references, this correlation shows that urban wind speed can help reduce sand stagnation with proper values of these parameters. Therefore, through the urban form study we can promote wind speed and blow away the accumulated sand till the urban limits.

Keywords: *Computational Fluid Dynamics (CFD), Sand accumulation, Saltation, Urban form, Urban geometry, Wake effect*

INTRODUCTION

Timimoun is a town and commune, and the capital of Timimoun District, in Adrar Province, south-central Algeria. The town of Timimoun lies at an altitude of around 288 metres (945 ft) in the Gourara region of northern Adrar Province (Bisson, 1957). It is located on southeast of an oasis, which supports the source of water for the town. A sebkha (salt lake) lies further to its northwest, while the plateau of Tademaït lies to the southeast. (Fig.1)

Like the arid regions of the world, Timimoun region now faces the thorny problem of sand accumulation Fig.2. This phenomenon is mainly caused by the severity of arid climatic conditions and the wrong choice sometimes of human settlements inside Erg. In fact, the wind is the key factor that is responsible for this phenomenon. The consequences on society and economy are serious: decline in agricultural production, migration, unemployment and lack of basic services; housing, health, education ...etc. (Kara, 2008)

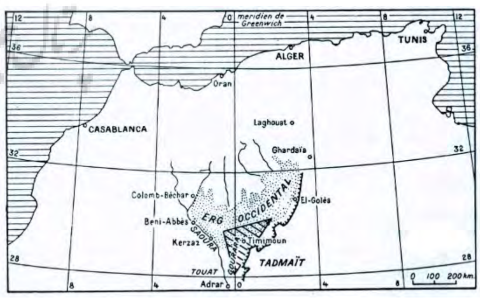

Fig. 1: Town of Timimoun. (Bisson, 1957)

Timimoun has a hot desert climate BWh (Köppen climate classification); with extremely hot summers and mild winters, and very little precipitation throughout the year. The silting

*Corresponding Author Email: *djamel.mestoul@yahoo.fr*

Fig. 2: human settlements inside Erg, town of Timimoun. 2012

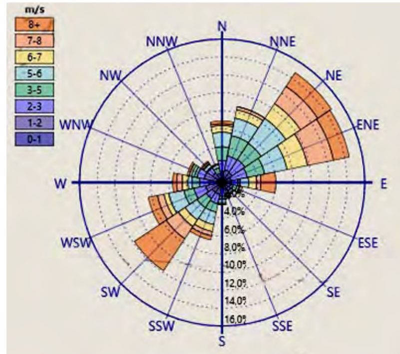

Fig. 3: Wind rose for the town of Timimoun (1995-2010). ONM-Dar-El-Beida, Algiers

is quite recurrent in the region Timimoun. This is due to the fact that this region is exposed to strong winds that can reach a speed of 8m/s in the northeast and southwest (Mestoul, 2011) Fig.3.

The objective of this research is to define an urban form that can fight against silting. This is an urban form that is able to present a "specific impact" on the movement of a local wind. This specific impact is corresponding to an aerodynamic mechanism to facilitate the passing of moving sand. The ventilation mechanism will be evaluated by the study of urban form parameters (e.g., aspect ratio H/D, E/D). These physical parameters are associated with a wind velocity of the order of 2 to 4m/s (saltation threshold).

MATERIELS AND METHODS

Given the fluid nature of wind, the most critical factor in controlling the airflow at the urban scale is the space geometry. All spaces between buildings, both horizontal spacing, the relationship of the building with its height, called the urban profile that determines the level of shelter or exposure to wind in urban environment through the pressure distribution (Ali-Toudert, 2000).

To understand the behavior of the wind within the urban form we made use of Computational Fluid Dynamics (CFD). The simulation will be performed with the code Fluent in which we chose the turbulence model (k-standard). This model is the most commonly used to simulate the mean flow characteristics in turbulent flow conditions.

Through the CFD simulation, we will try to define the aspect ratio (H/D) and (E/D) of urban form, which is capable to maintain a wind velocity the order of 2 to 4m/s in the built environment. This velocity will be able to blow away the sand grains with a diameter of 50 micrometer (saltation mode) from the urban area.

RESULTS AND DISCUSSION

Case of Simple Row of Volumes

Based on the theories of (Bouvet, 2003) and (Duchemin, 1958), we chose a series of volumes that have the same dimensions defined in the Table 1 and it is found as the one with the least sand accumulation.

Table 1: Characteristics of the tested model (type A).

Name of model	Height (H) [m]	Length (L) [m]	Distance between volumes Δ [m]	Ratio H/L	Ratio L/Δ
Type (A)	5	10	15	0,5	0,66

The simulation of the airflow around this body movement is shown in Fig.4. The results of simulation seems to support the hypothesis of (Bouvet, 2003) following which the upstream accumulation with body is not important. This results in the movement of side wind is easily dissipated through the opening of the field between the marked volumes. This distance (Δ) is about 3H, and the ratio of building length to the building separation (L/Δ) is approximately 0.66 (Table1).

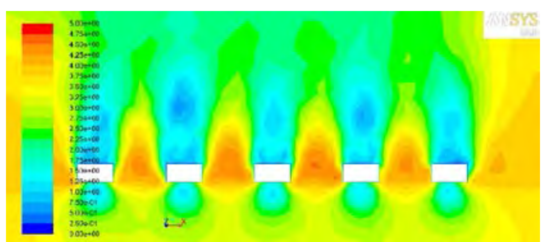

Fig. 4: graduating speed around volumes type B.

However, at the upstream/downstream side, the wind tends to decelerate because of the wake effect, which occurs at the upstream/downstream of the volume. This wake effect is shown in Fig.5. In this figure, using a representation air by arrows we see that a wake effect is created in the zone 1 due to the buffering of the air against the edge of the volume (A). Then in the zone 2, air tends to turn back in zone 2 before hitting against the leeward side (zone 3). Therefore, zone 1 and 3 will be necessarily accumulation areas once the air velocity is zero. It means that in these areas the air can be discharged and can give rise to sand accumulation, called sediment.

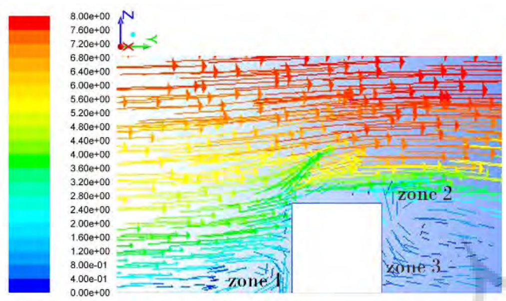

Fig. 5: graduating air velocity around a simple volume type A on the ground.

Our objective in this step is to make a modification in zone 3 (wake effect) to avoid sand accumulation in zone 4. This means to take some action to remove the wake effect in the downstream airflow of the volume.

For this, we conducted a built-on-stilts volume type (A) to release the compressed air in the pressure zone of the wind, and transform the potential wind energy into a kinetic energy. The airflow will have to pass under the volume and disappear wake effect in zone 2. Zone 3 will no longer be an accumulation zone. In the simulation, we took the same series of volume type A defined above in the Tab.1 and in this time we raised them a height of 3m from the ground. (Fig. 6)

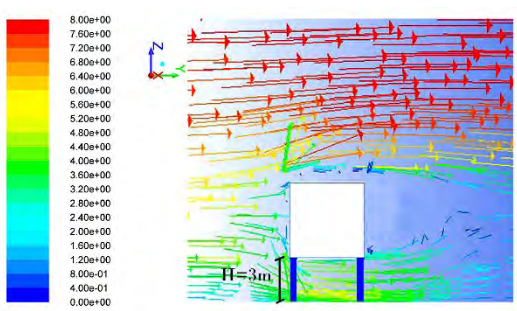

Fig. 6: graduating air velocity around raised volume type (A), h = 3m.

The Fig. 7 shows from a plan view the result of comparison between a row resting on the ground and the elevated volumes of 3m from the ground. We found that the volumes on stilts have a wind velocity much higher (sometimes up to 6m/s) than those placed on the ground, near the ground behind the volume as well as to between the rows. This is explained by the fact that the pressure is released under the raised volume and later transformed into kinetic energy, which could remove the wake interference and reinforce the initial speed of 3m/s (green) to 6m/s (red).

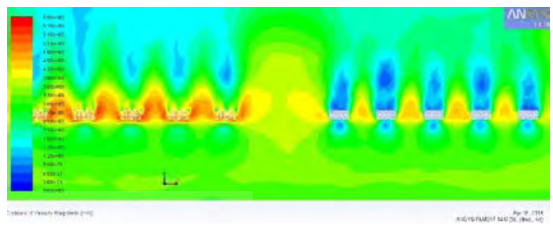

Fig. 7: Plan view of airflow for a series of raised volumes type (A) (left) and volumes placed on the ground (right)

Case of a Several Rows of Volumes (Urban Form)

In the former experiment, the ratio between the length of building and the spacing between two buildings (L/Δ) is 0.66. In the second part of our research, we will address the issue of airflow behavior with several rows of volumes type (A). Our aim is to find relation with the spacing between the rows. In addition, the ratio H/D and E/D play an important role on the urban density of our future prototype. We define here W as the building width, H the height, L the length, D the spacing between two adjacent rows and E the urban length. (Fig. 8)

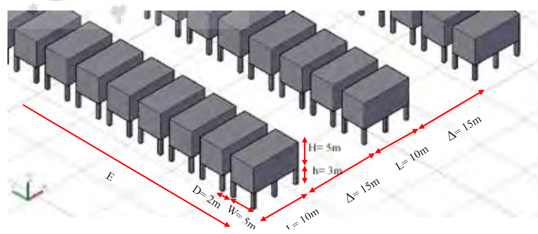

Fig. 8: urban form model consists a several rows of type (A) volumes.

The research led by (Oke, 1988) count among the most detailed work on the impact of an extensive urban area on airflow. Oke studied the impacts of the urban density, with varying ratio of H/D The wind flow within an urban canyon is a secondary circulation driven by the dominant wind above the roof (Nakamura & Oke 1988, Santamouris et al., 1999). It is strongly affected by the street orientation and the geometry of buildings. When the flow over arrays of buildings is approximately normal to the street axis, three regimes can take place depending on the aspect ratio (H/D) and building ratio (L/D). These regimes are respectively isolated flow regime, wake interference regime and skimming flow regime (Oke, 1988) as shown in Fig. 9.

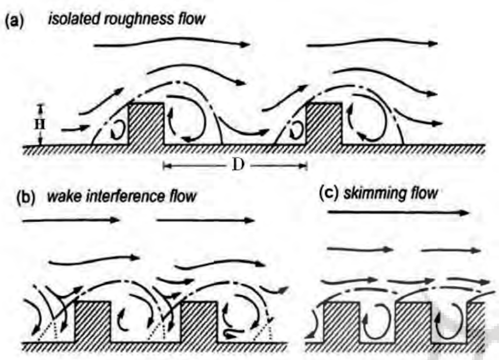

Fig. 9: Three regimes airflow in function of canyon aspect ratio and building geometry (Hosker, 1985).

The transition from one regime to another occurs at some special values of H/D (Hussein & Lee 1980) and L/D (Hosker, 1985). The spacing between the upwind buildings is a factor that can modify the flow from the isolated regime to the interfere regime. However, when the buildings are long, the front spacing shows little impact. In the same way, Hosker (1985) finds that the transition between the flows depends on the function between the canyon ratio (H/D) and the building geometry (L/H). However, the role of canyon ratio (H/D) is dominant, while (L/H) is inferior. (Fig. 10)

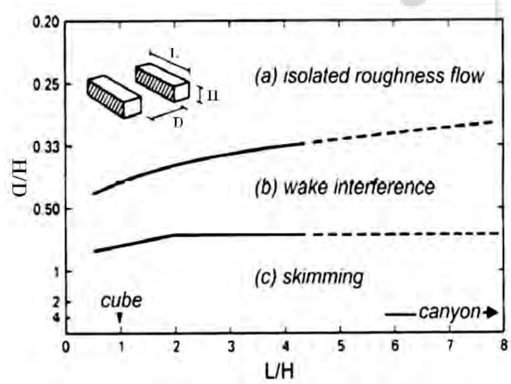

Fig. 10: Wind flow regimes depending on the urban profile (H/D). (Oke, 1988)

To have a skimming flow requires that the ratio H/D has a value greater or equal to one (Fig. 9). That is to say, smaller array gap (D) (tight buildings) presents a flow more skimming. Therefore, the airflow passes over the roof without interference between buildings. In this third part of our research, we focused on the study of the behavior of wind within an urban form that consists of several series of volumes with dimensions shown in Table 2.

Table 2: Characteristics of prototypes of studied urban forms.

Models	Volumes Height (H) [m]	Volume Width (D) [m]	Spacing between volumes (Δ) [m]	Spacing between rows (D) [m]	Number of rows	Elevation from the ground (h) [m]
(1)	5	10	15	2	15	4
(2)	5	10	15	2	15	3
(3)	5	10	15	2	15	2

Rows of volumes are separated with a small distance (D=2m) that allows to produce a skimming flow above the building and avoid the interference between the buildings that can produced accumulation of sand between buildings.

The urban form we used for modelling is all composed of volumes type A, which is raised above the ground (h=2, 3 and 4m) and whose dimensions have been defined in Table 1. We modeled this urban form in Fluent to see its interaction with an airflow of 8m/s (given Timimoun's weather). The input velocity is defined according to the user-defined function (1) "udf.h" in Fluent. The roughness coefficient in the power law wind profil was chosen 0.3, and turbulence model, we have chosen (K-□) standard was chosen for its general satisfying performance.

$$U_z = Uo *(Z/ Zo)^a \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$U_o = 8m/s,\ a=0.3,\ Z_o=10m,$$

We varied the elevation height of the stilts of the volume type A to see if there is an improvement in the speed of the air passing through the urban form under its raised volume. The goal is to test the impact of elevation from the ground on the wind speed under the raised buildings. In addition, we try to observe which urban length (E) can keep the speed to a threshold of saltation either (2 to 4.5 m/s). According to the literature (Bagnold, 1941; Pethick, 1984; Anderson & Haff 1991;Kok & Renno

2009), we suppose that this velocity would still be able to put in motion the accumulated sand grains under the raised buildings remove them.

Fig. 10 illustrates perfectly the difference in terms of profiles of wind velocity within the three types studied. Unlike model type (2) and type (3), the model type (1), shows a wind with speed of 5m/s (green) at the entrance under the buildings on stilts which gradually decreases from the fifth row to smaller than 2 m/s at the end of the eighth rows of the buildings. This wind with a speed up to 5m/s is assumed to be able (according to our theoretical studies) to deliver by moving saltation the accumulated sand grains under and between buildings. It seems that the model type (1) (raised 4 m above the ground) can produce a wind velocity of 2-5m/s witch is able to lift the accumulated sand in buildings. However, this velocity tends to decrease as the wind passes through the overhead buildings. We note that it can even equal to zero at the end of the sixth row. (Fig. 11)

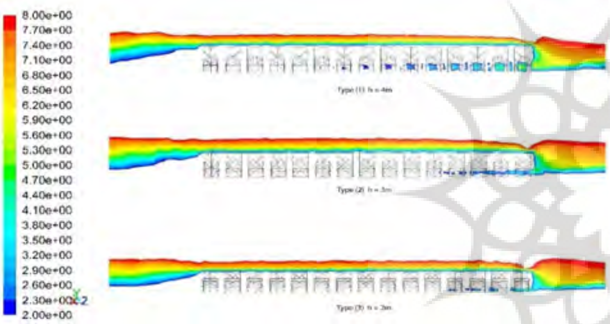

Fig. 11: Longitudinal section showing contours of wind in velocity (m/s) under buildings for the three urban form models.

Velocity less than 2m/s means that the sand grains deposit. We tried a second urban form with only six rows (spaced always 2m) and observe the impact on the evolution of wind velocity under buildings. Our interest would be to have a wind with velocity not less than 2m/s (saltation threshold) travelling all along the urban length (E).

The results in Fig. 12 and Fig. 13 shows clearly that with an urban form of six rows of buildings the wind passes under the buildings with a velocity of 4 m/s. This velocity tends to gradually stabilize around a value of 2 m/s from the end of the fourth row until the end of the sixth one.

With this urban form prototype, (type 1 in Table 2) wind can pass through an urban length (E) of approximate 40 m with an initial velocity of 8m/s. This speed tends to stabilize around a value of 2m/s and maintained it self-cross along the urban length (E = 40 m). According to the literature, the wind of 2 to 4.5 m/s in the built environment could keep the moving sand in saltation without deposition.

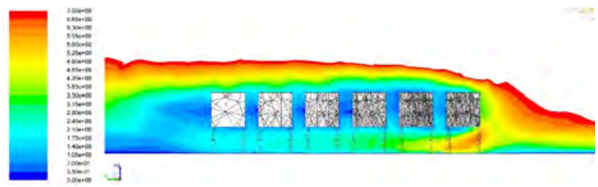

Fig. 12: Wind velocity contours around buildings in an urban length E with six rows.

CONCLUSION

According to our investigation in 2012 on the site of Timimoun, we found that the sand accumulation problem in these areas is due in most of the time to the mechanism of saltation that can start with a wind of 2 to 4.5 m/s.

This problem of sand accumulation is clearly the most difficult to confront not only because it occurs at regular frequencies of regular wind regime. This phenomenon is amplified by other physical factors associated with the urban form morphology (H/D, E/D).

In our present modeling, we are interested in the question of accelerating the wind velocity in the general plan. The aim is to ensure a minimum speed not less than 2m/s to avoid any deposition of sand between buildings.

We have tested several models with the code Fluent and defined the ratio of H/D and E/D in the promising model (1) (Table 2). This model (1) is an urban form compound of six arranged buildings spaced 2m. Each row comprises five volumes, spaced (Δ) 15m with a dimension L=10m, W=5m, H = 10m and h=4m. This model maintains a constant wind velocity not less than 2m/s under and between raised buildings. According to our theoretical studies, this speed is capable of moving the accumulated sand and remove it out of the urban area (E =40m) with six rows of buildings. (Fig. 13)

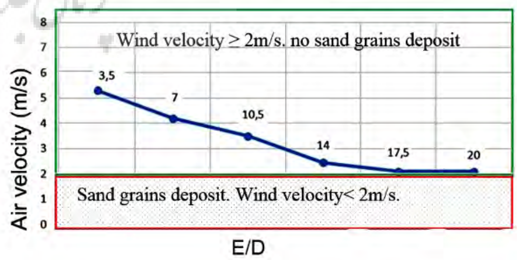

Fig.13: Profiles of air flow velocity according to the urban length/Spacing between rows of volumes.

Our future research is to test the relevance of this model by introducing the sand material in the simulation. In addition, the visualization of the disposal areas would help us to judge the relevance of the model.

ACKNOWLEDGEMENTS

Thanks are due to Biao Wang Ph.D. Student at LRA-Toulouse for his help in simulation with Fluent. Thanks are also due to Office National de Météorologie (ONM) de Dar El Beida of Algiers for providing the 15 year (1995-2010) data of Timimoun for analysis.

ENDNOTES

1.Erg:a vast area covered with sand and shifting dunes, as parts of the Sahara Desert.

2.BW - dry arid (desert) is a true desert climate. It covers 12% of the Earth's land surface and is dominated by xerophytic vegetation. The additional letters h and k are used generally to distinguish whether the dry arid climate is found in the subtropics or in the mid-latitudes, respectively.http://www.physicalgeography.net/fundamentals/7v.html

REFERENCES

Ali-Toudert, F. (2000). *Intégration de la dimension climatique en urbanisme.* Mémoire de Magister, EPAU, Alger.

Anderson, R. S., & Haff, P. K. (1991). Wind modification and bed response during saltation of sand in air. In *Aeolian Grain Transport 1* (pp. 21-51). Springer Vienna.

Bagnold, R. A. (1941). The physics of wind blown sand and desert dunes. *Methuen, London*, 265(10).

Bisson, J. (1957). Le Gourara. Étude de géographie humaine. Alger.

Bouvet, F.N. (2003). *Approche macro-structurelle des écoulements bi-phasiques turbulents de neige et de leur interaction avec des obstacles.* (France).

Duchemin, G.J. (1958). Essai sur la protection des constructions contre l'ensablement à Port-Etienne (Mauritanie).

Hosker, R. P. (1985). Flow around isolated structures and building clusters: a review. *ASHRAE Trans.;(United States),* 91(CONF-850606-).

Hussein, M., & Lee, B. E. (1980). An investigation of wind forces on three dimensional roughness elements in a simulated atmospheric boundary layer. *Dep. Build. Sci. Reports BS 55, 57.*

Kara, M.K. (2008). La menace climatique en Algérie et en Afrique ; les inéluctables solutions. Éd. Dahleb. Alger, Algérie.

Kok, J. F., & Renno, N. O. (2009). A comprehensive numerical model of steady state saltation (COMSALT). *Journal of Geophysical Research: Atmospheres,* 114(D17).

Mestoul, D., Bensalem, R., Boussoualima, D., Daoudin, S., Lamaraoui, S., Khalifi, L., & Adolphe, L. (2011). Pour une caractérisation des phénomènes extrêmes des changements climatiques en zones arides ; cas de l'ensablement à Touat-Gourara en Algérie. Journees Scientifiques, 4-8 April, Campus 2iE Ouagadougou, http://journees-scientifiques.2ie-edu.org/js2011/sessions/pdf/mestould.pdf.

Nakamura, Y., & Oke, T. R. (1988). Wind, temperature and stability conditions in an east-west oriented urban *canyon. Atmospheric Environment* (1967), 22(12), 2691-2700.

Oke, T. R. (1988). The urban energy balance. *Progress in Physical geography,* 12(4), 471-508.

Pethick, J. (1984) An introduction to coastal geomorphology, Edward Arnold.

Santamouris, M., Papanikolaou, N., Koronakis, I., Livada, I., & Asimakopoulos, D. (1999). Thermal and air flow characteristics in a deep pedestrian canyon under hot weather conditions. *Atmospheric Environment*, 33(27), 4503-4521.