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Comparative Wind Simulation Studies of Different Urban Patterns in Hot Arid Region: Touristic Resort at Qarun Lake, Fayoum Region, Egypt

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Abstract

Nowadays, it is considered that urban areas consume the bulk of vital natural and energy resources that raise concerns of environmental deterioration on different scales. Now, worldwide energy assessments indicate that improving the energy efficiency and sustainability of buildings, and urban communities could free-up enormous amounts of current energy expenses. Those energy fluxes and change of airflow that resulted from urban morphology can lead to phenomenon such as the urban heat island and convective rainfall initiation.

In this research it initiates – Urban Fluid Mechanics (UFM) by using Computational Fluid Dynamics (CFD) tools that delve into fundamental fluid flow problems of immediate utility for the development of resorts at Qarun lake in Egypt through a comparative study between different urban patterns through three main processes. Firstly, it starts by using of results from a mesoscale model to indicate the best place for building a wind turbine farm and to generate data for the microscale model of the urban canopy. Secondly, using qualitative modeling method for urban analysis that can evaluate the airflow conditions of the urban canopy in different seasons. Thirdly, making a comparative study between different urban patterns by changing a certain parameter. As a result from these three processes that qualitative simulation process will be of use for building and urban scale performance predictions as well as for the future simulation of pedestrian comfort. In this paper, it describes in detail one such approach, along with some sample results demonstrating the capabilities of this tool in Planning and urban design decisions, and raises questions as How Architects, Planners, Urban designers get advantages through using CFD method and its tools?, How can that method indicate the best places for renewable energy resources? and How can such ways of comparative studies can but a certain criteria for urban design in a certain zone?

Key words: The shading edges; Urban morphology; Land cover; CFD applications; Street canyon; Wind barrier; Livable city; Urban Fluid Mechanics (UFM)

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INTRODUCTION

In the late of 1970s, Building and Urban simulation started to stand out as a separate discipline. It draws its underlying theories from mathematics, physics, material science, behavioral, and computational sciences (Malkawi and Augenbroe, 2003). Nowadays, climatic simulation of Buildings and Urban areas is a complex task, the simulation process of which is not understood clearly until now. However, there are major improvements that have taken place in modeling, meshing, and iteration process. These improvements make climatic building simulation is continuously evolving and maturing to over its difficulties (Rasheed and Robinson, 2009). As Architects, Planners, Environmental researchers and Scientists try to get approaches to study the Air Flow Pattern (AFP). According to Mirzaei and Haghighat, these approaches and techniques are divided into: (i) Observational approaches; (ii) Simulation approaches. Recently, due to extensive computer progress and limitations of observation methods, researchers focused more on simulation approaches such as CFD. On other side, these tools have difficulties, including high computational cost of simulations and shortcomings in providing high-resolution, continuous and real time boundary conditions. For that it needed to get progress on models integration by taking advantage of multi-scale models and to be compatible with each other. As a result these tools can be useful for planners, urban designers and political decision makers.

1. THE SIMULATION PROCESSES

1.1 First Stage: The Meso Scale Model Data and Analysis

Qarun lake is considered the deepest part of the fayoum depression in the western desert of Egypt. As stated by Hemeida.E.I (1996), Qarun lake is located 80 km south west of Cairo, and at the south of the Mediterranean coast of Egypt by 320 km. It is confined between 29° 25' N latitude and 30°25' longitude (as shown in figure 1).

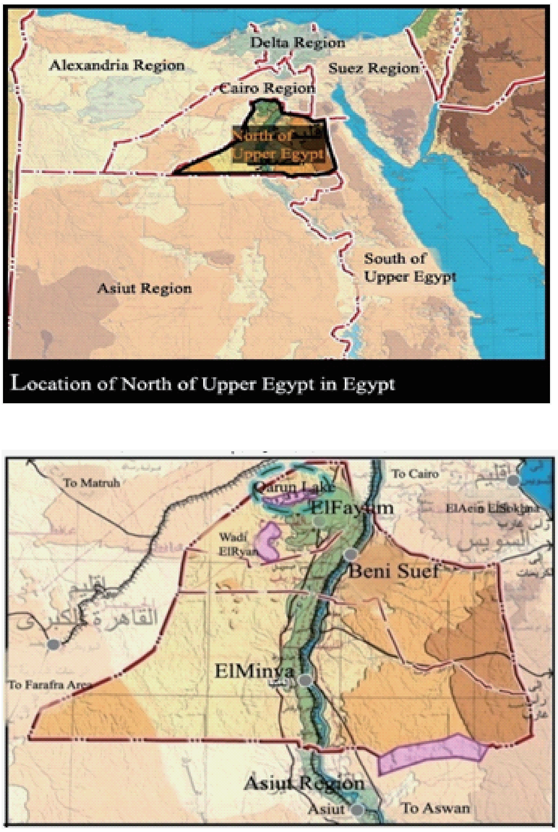


Figure 1
Qarun Lake and Fayoum Depression in Egypt (ElBaz, 2007)

The meteorological data that were obtained from the meteorological stations represent the general trends and seasonal variations of the climatic conditions in the region close to the lake as measured and observed by Abdellah, R. (2009).

According to Abdellah, R., the study area lies in the western desert region and it is characterized by the continental climate. As the monthly average values of air temperature, relative humidity and evaporation are calculated as means from the daily readings in every month, The maximum air temperature (37.3°C) was observed in August, while the minimum (14.4°C) was recorded in January. The difference between these two extremes was 22.9°C. (Abdellah, 2009) In Data input process it depends on wind data from an average of 10 years (1998 to 2008) from several stations. These data obtained from Radwan G. Abdellah from NIOFE (National Institute of Oceanography and Fisheries, 2009).

This wind data had analyzed from the Excel sheets on Surfer and Grapher software, as shown in figure 2 that shows the August wind readings and results as they have the highest temperature in the year considered, in August month, and the Maximum of wind velocity rate that reaches to about 40 m/s. The average of wind speed in August is about 5.4 m/s and lowest wind speed of about 1.2 m/s.

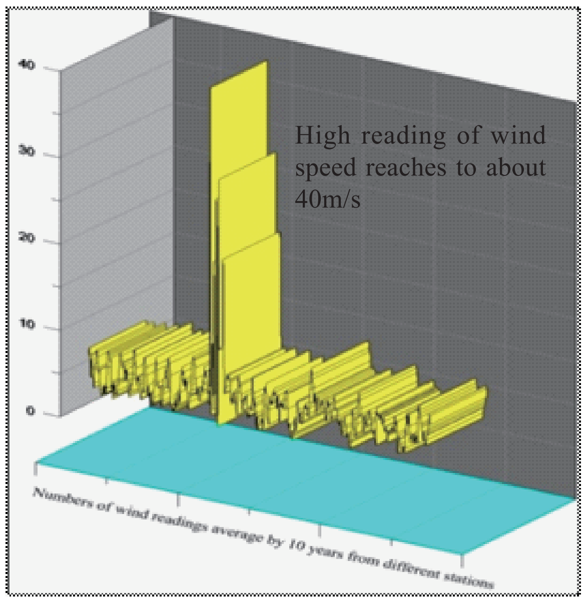


Figure 2
Ten Reading Analysis of Wind Profile in August

1.2 Processing Stage of Meso Scale Model

The wind data is used as inlet data for generating the CFD process. That stage includes also defining the 3 processes undertaken for setting the working model:meshing and generating grid cells, boundary conditions, and iteration process.

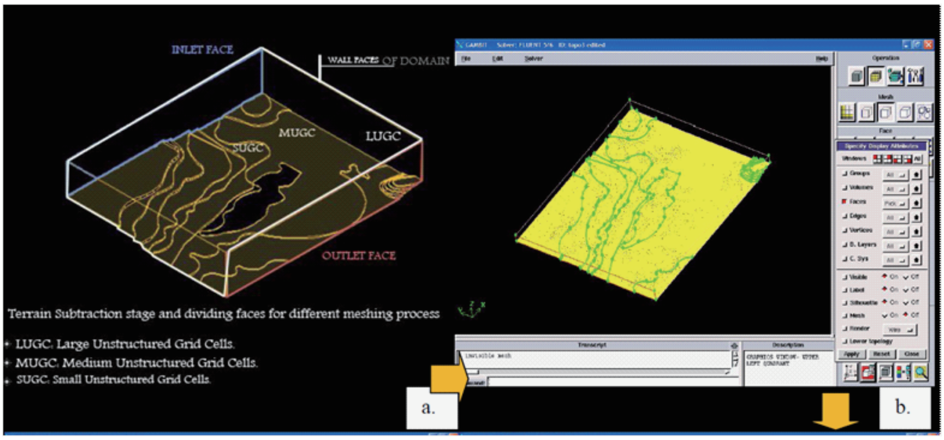
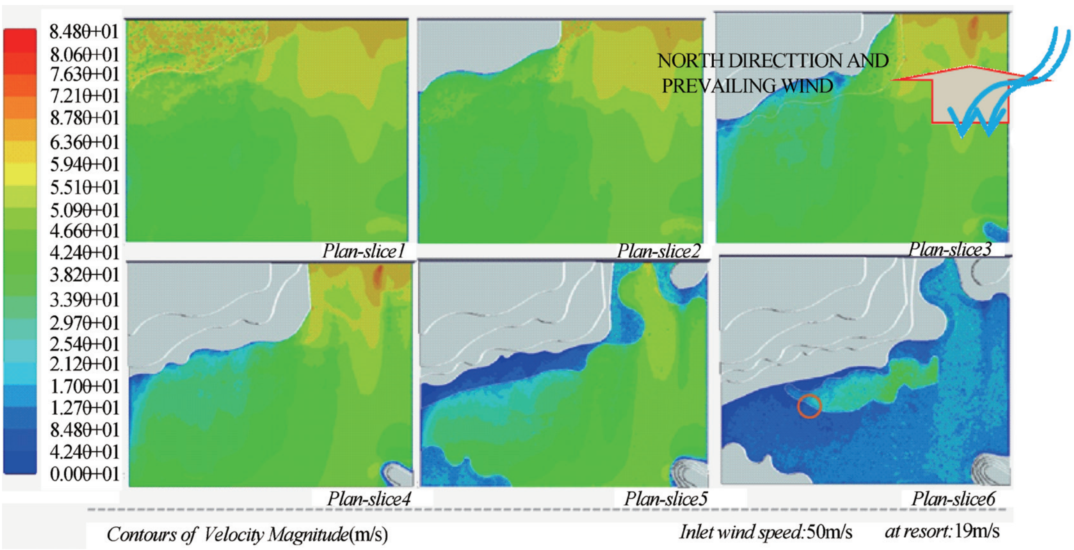


Figure 3
Dividing Model Faces to Categories for Grid Cells Generation Process

As shown in figure 3 that shows the meshing process of the model, the boundary conditions of the model define the inlet face of the wind and the outlet face as in wind tunnel experiments.

In the study of that case, it discusses the results of meso and micro scale studies in the month of August. The reason behind the choice of this month, is that it presents the extreme weather conditions in the resort area, and is also one of the busiest month of the year for the resort besides February and May. For the Meso scale study undertaken in August, the study analyze several readings that be taken to present different wind speeds in that month. As shown in figure 4, the wind speed study based on data of the last ten months.



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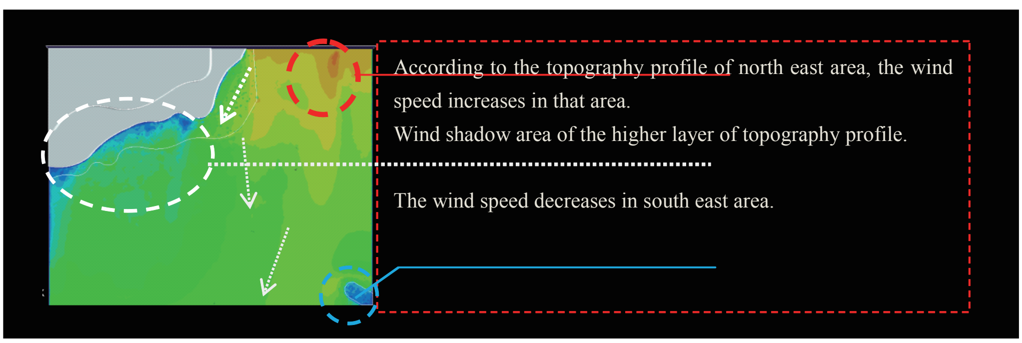


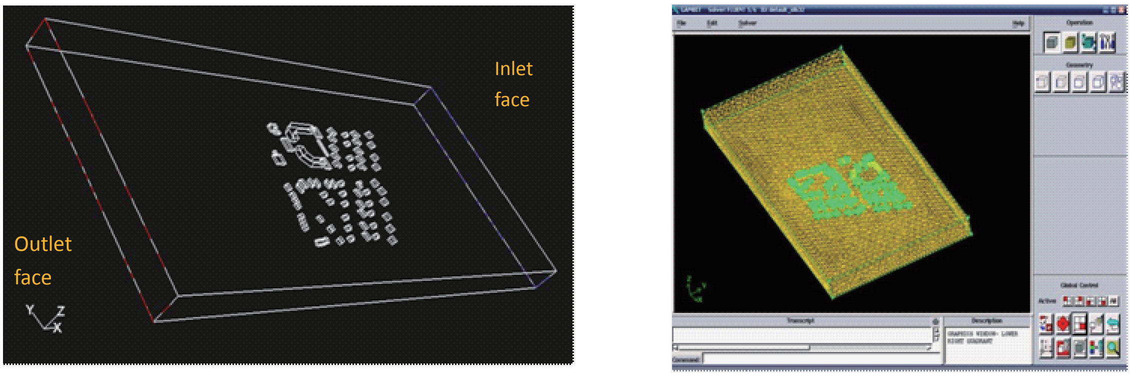
b

Figure 4
a. CFD Results for Wind Speed in August at Highest Wind Speed;
b. Increasing in Wind Speed at North East Area in August

The wind output data from the meso-scale has provided the possibility to set the boundary conditions according to the actual wind environment for micro urban model. Furthermore, it is being founded that north east zone is the best zone for building wind turbine farm for generating renewable energy.

1.3 Second Stage: The Simulation of the Micro Scale Model

The micro scale model is a recreational resort in the western area at the south coast of the lake, that model divided according to: a. Domain and the boundary conditions: The domain of the Urban model has resolution of 959m×579m, with height of about 50 meter. For scientific and practical accuracy, the turbulence model that is used is K-epsilon RNG model. This type of model is relatively quick and easy to solve, and can provide good accuracy level for the flow setup; b. Meshing and grid cells generation: As a result, the number of the grid cells is about 101773 tetrahedral cells (shown in figure 5).



a b

Figure 5
a. The Domain and the Boundary Condition of the Resort Model
b. The Meshing Process at Gambit Software User Interface

The micro scale studies will focus on the readings from the meso scale study in August that will take 19m/s as inlet wind speed in such case.

These studies will divide the urban pattern of the resort into three main parts:

(1) P1is the southern area in the resort that formed from:

a. The hotel, in the southern western area.

b. Services buildings adjacent to the hotel.

c. Main management building at the southern area.

d. Part of last row of units..

(2) P2 represent the last zone of units and villas in the southern eastern areas.

(3) P3 represent the first rows of the units. The P3 units will experimental studied by changing number of detached clusters, and the angle of direction.

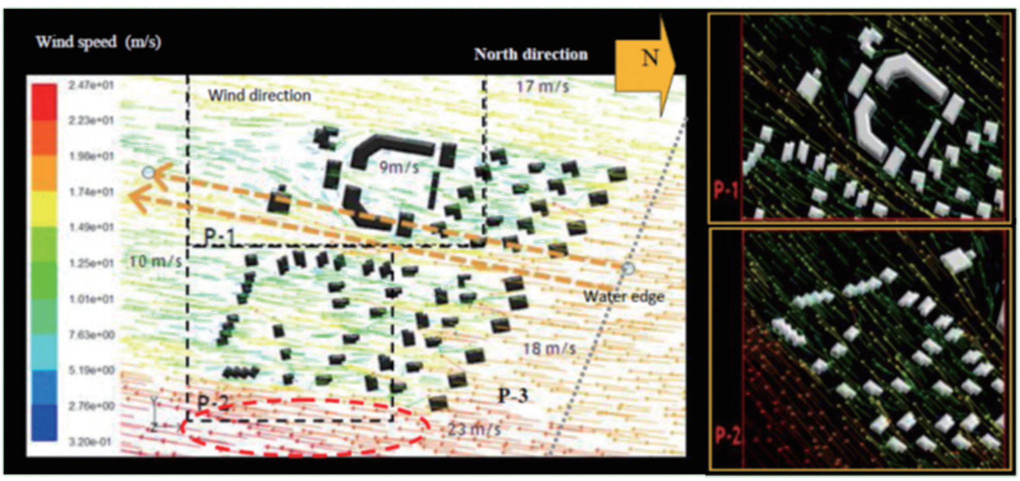


Figure 6
CFD Study of AFP in August at High Wind Speed and Show Dividing the Resort into Three Parts (P1, P2, P3)

As shown in figure 6, the AFP in August month described as the wind speed increase in the east area to about 23 m/s, decreasing at the southern area to about 10m/s as the wind shadow of P1 and P2 increase.

1.4 Third Stage: The Micro Scale Comparative Study and the Validation Process

As discussed that the resort divided into three main parts, P3 area that include the first three rows of resort units taken in two comparative studies: Comparative study of oriented units with different angles. The comparative study is depended on the table of Ashrae.

Table 1
The Parametrical Criteria of Validation Process of the Comparative Study Based on the Beaufort Scale (Penwarden, *et al*., 1975)

Description of wind	Speed (m/sec)	Description of wind effects	Validation rates
Calm	Less than 0.4	No noticeable wind	Bad
Light airs	0.4-1.5	No noticeable wind, but air can be felt to be moved	Medium
Light breeze Gentle breeze	1.6-3.3 3.4-5.4	Wind felt on face; Wind extends light flag; Hair is distrubed	Good
Moderate breeze Fresh breeze	5.5-7.9 8.0-10.7	Wind raises dust; Force of wind felt on body; Limit of agreeable wind on land	Medium
Strong breeze Moderate breeze Fresh gale	10.8-13.8 13.9-17.1 17.2-20.7	Difficult to walk steedily; Inconvenient felt when walking; Great difficulty with balance in gusts	Bad
Strong gale	20.8-24.4	People blown over by gusts	Very bad

As shown in table 1, the measurement of the parametrical study is divided by the effect of the wind speed on pedestrian human comfort, these data divided measurement tool to good AFP, medium AFP, bad AFP, and very bad AFP as dangerous wind speed values.

In the comparative case studies, the inlet wind speed is about 13 m/s. That wind speed make AFP range from about 0.2 m/s to 19 m/s, that will be indicated by AFP module as to be good, medium, or bad.

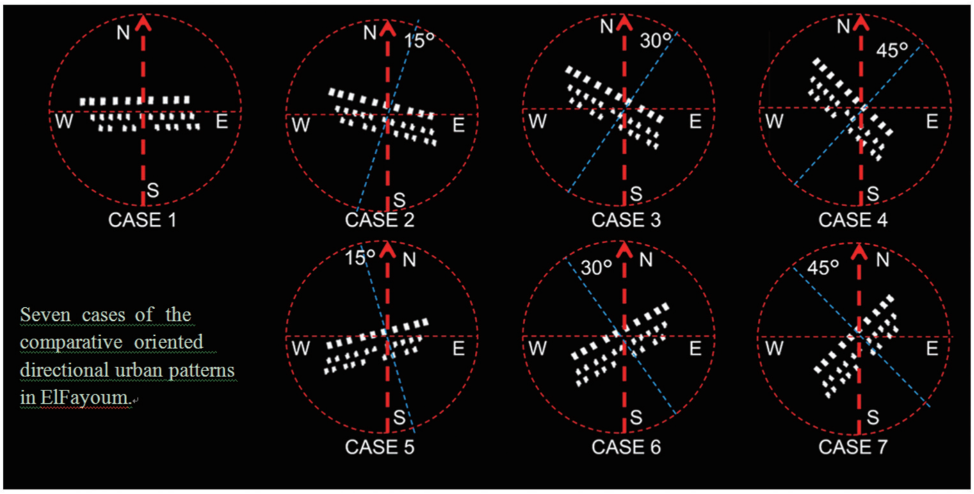


Figure 7
The Seven Cases of the Comparative Study

As shown in figure 7, that comparative study is divided into seven case studies:

CASE A: The urban pattern is perpendicular to the north.
CASE B: The urban pattern is angular to the east by 15°.
CASE C: The urban pattern is angular to the east by 30°.
CASE D: The urban pattern is angular to the east by 45°.
CASE E: The urban pattern is angular to the west by 15°.
CASE F: The urban pattern is angular to the west by 30°.
CASE G: The urban pattern is angular to the west by 45°

Perpendicular direction case is validated according to Ashrae report, the domain is divided into 10 interval distances in the Y-direction and 8 section lines that show change of wind speed in the graph. In general, in that case the urban pattern is perpendicular to the wind, high difference in pressure between windward and leeward sides lead to high wind speed that reach to about 17 m/s. The wind speed ranges from 3m/s to 6m/s that can be considered good in hot arid regions for pedestrian comfort and ventilation, such ranges reach to about 4% from the whole wind speed value grid system (as shown in figure 8).

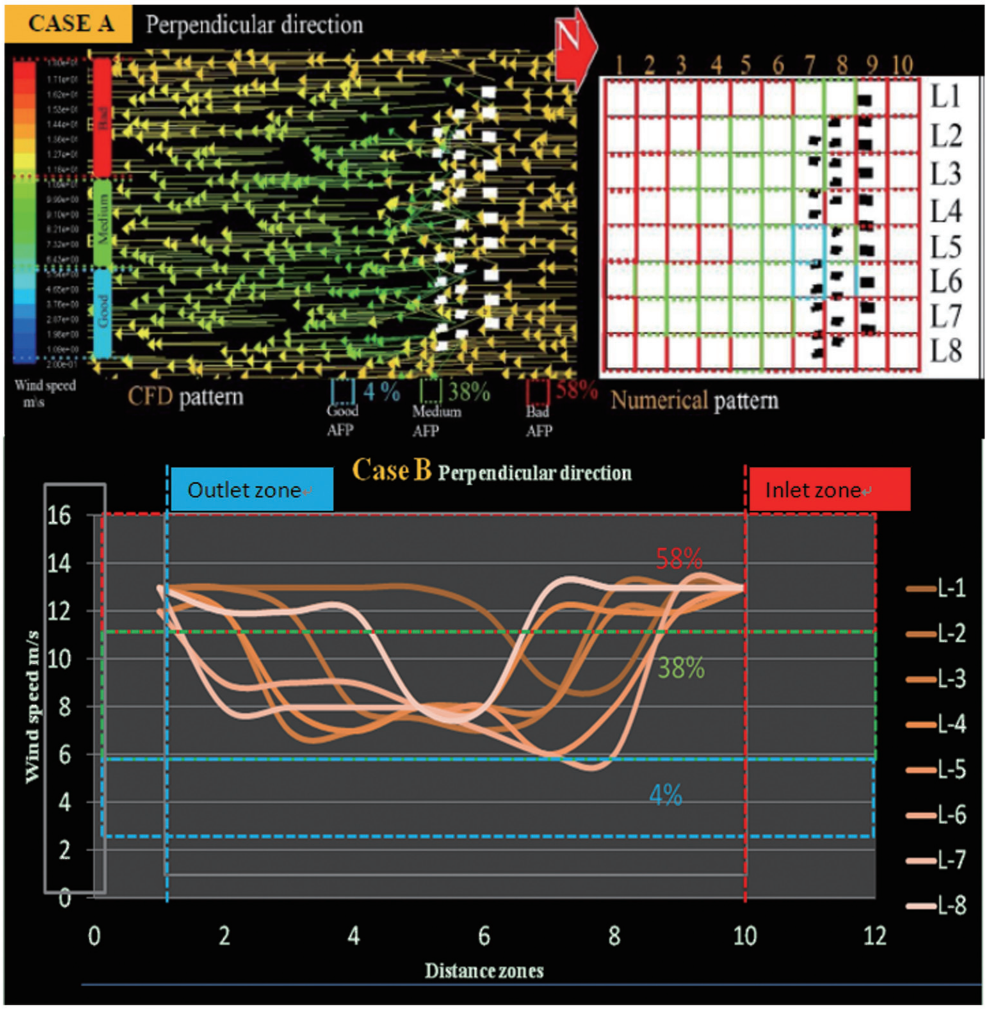


Figure 8
Case A- Perpendicular Direction-Parametrical Study

Results show that: 30° angular direction to east (Case C) is the best AFP performance in the study, and perpendicular to north direction (Case A) is the lowest case of AFP performance (as shown in figure 9).

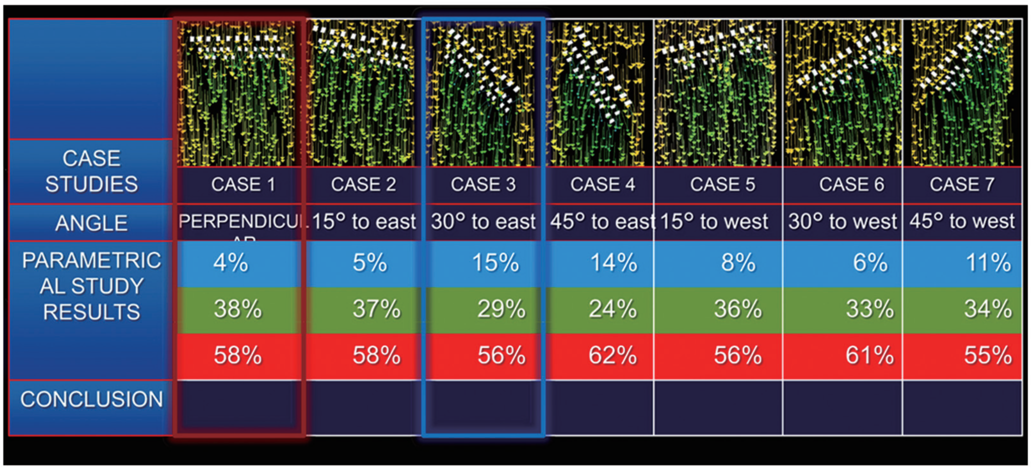


Figure 9
Comparative of the Seven Case Studies

CONCLUSION

The relation between scientific methods and application methods of CFD process can integrate in different ways to develop environmental planning and urban design decisions that will give new solutions for urban communities and outdoor pedestrian comfort. Also, CFD simulations can be beneficial for taking decision of where the best places to use for renewable energy.

The computational requirements for the use of advanced numerical methods and models are become available. All the work in this project has been performed on PC using a dual processor machine. Limitation in memory have limited the meshing resolution, and is hence the main source of error. The usage of the PC shows how accessible CFD models are to general users, and the need for specialist workstations has effectively been removed. In actual application, a balance between the precision and the time cost also should be taken into consideration. All in all, the wind environment simulation is a complicated problem which is still under research but it has a bright future for fields as Architecture, Urban design, and Planning process.

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