Chapter Seven

Modeling and Simulation

7.1. Introduction

This chapter aims at studying wind pattern in a real residential area. In this area, the buildings are designed and constructed according to Khartoum State building regulations.

Two pilot models for a room are done firstly to train on how to carry out the analysis and simulation on the study area which draw many buildings. This chapter also tends to help planners distribute residential plots and the ventilation needed for each building. This can be achieved by specifying the roads width, height and distance between buildings and the height of the boundary wall between plots. It also aims at arriving at a rule to enable architects to design residential buildings, which ensures availability of the air flow.

Although the CFD is available for use in the scientific research fields as analysis and design tool anywhere around the world, it hasn't been used widely in Sudan.

The researcher has installed a copy of CFD in his computer after the internet for the price of this software which is very expensive. Firstly, it was difficult for the author to use and analyze the wind pattern around the buildings because the CFD is based on highly complex mathematical equations. Therefore, two pilot models are analyzed at the beginning of the analysis to train on how to conduct analysis and simulation.

7.2. Wind Data Analysis

Wind data has been collected from Meteorological Authority in Khartoum international airport, Sudan, in the period between January 2009 and November 2014. This data was analyzed to find out the dominant direction of wind flow over the different seasons. The data was analyzed using a computer programme, to examine the mean velocity around. The average wind speed during five years is 4.34 m/s while the dominant direction ranges between north to south.

Table 7.1. Wind data (Source: Meteorological Authority, Khartoum international airport, Sudan)

	2009		2010		2011		2012		2013		2014	
Element	wind		wind		wind		wind		wind		wind	
month	Dir	Speed (m/s)	Dir	Speed (m/s)	Dir	Speed (m/s)	Dir	Speed (m/s)	Dir	Speed (m/s)	Dir	Speed (m/s)
January	N	4.5	N	4.5	NNW	4.5	N	5	N	4.5	N	4.5
February	N	4.5	N	4	N	5.5	N	5.5	N	4.5	N	4.5
March	N	4.5	NNW	3.5	N	5.5	NNW	5.5	N	4.5	N	5
April	N	4	N	4.5	N	5	N	4	N	3.5	N	4.5
May	NNW	5	NNW	4	N	4.5	N	4.5	NNW	3	N	4
June	SW	4	SW	4.5	SSW	4	SW	4.5	WSW	3.5	WSW	3
July	SW	5	SW	4.5	S	5	SW	5	SW	4.5	SW	5
August	SW	4.5	SW	5	SW	4.5	SW	5	SW	4	SW	4.5
September	SW	4	SW	4	SW	4	SW	4	SW	4.5	S	4
October	NW	3.5	N	3	N	3.5	N	3	NNW	4	S	4
November	NNW	4.5	N	4	N	4.5	NNW	4	NNW	4	N	4.5
December	N	4	N	4.5	N	4.5	N	4.5	N	4.5	N	4.5

NOTE: N =north, S= south, W = west, E = east, Dir. = direction,

7.3. Description of Study Area

The area of Al Haj Yousuf, Block 10, East Nile Locality, Khartoum is 24.44 hectare, (244.420 m2), (505x484m). Block 10 consists of 242 third class plots. The houses are separated from each other with a fence of 1.5 to 2 m height. The area of a plot is 400 m2 (20x20m). The built up area ranges between 160 to 220 m2. The height of houses ranges between one up to three stories, but the majority houses is only one storey. The maximum height allowed in the third class residential area is four stories (ground + three stories).

Most houses are built in the center of the plot, and some of them attached to the fences.

The streets are 15- 20m in width. There are open spaces for social activities with area of 4600m2 (0.46 hectare). Figures (7.1), (7.2), (7.3)

Figure 7.1: Aerial view of the study area. [Author]

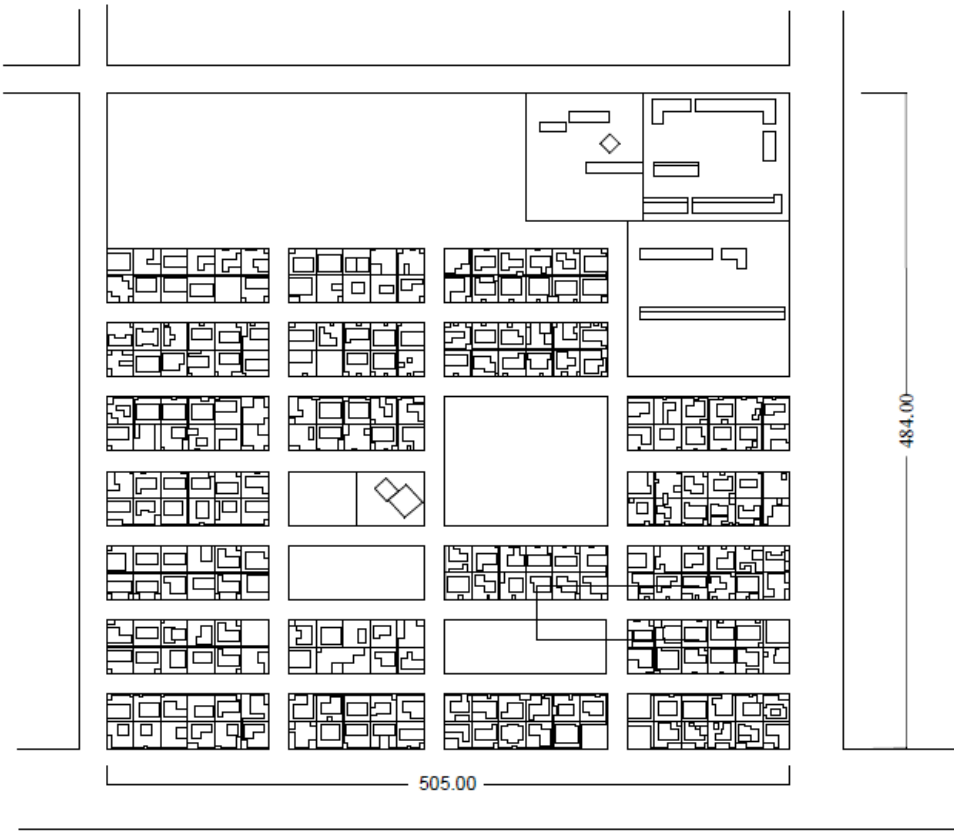

Figure 7.2: Plan of study area. [Author]

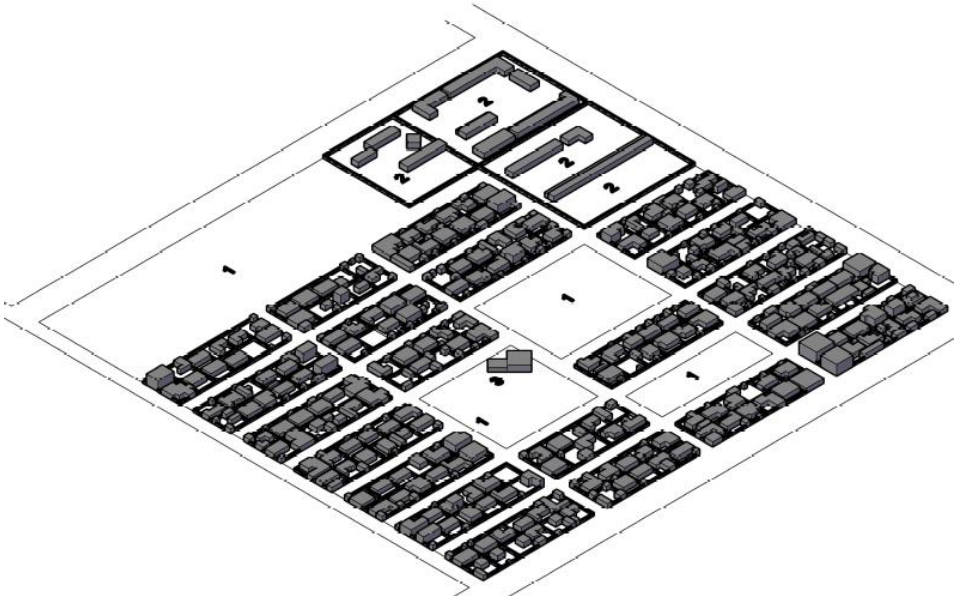

Figure 7-3. 3D view of study area. [Author]

1= Open space, 2= School, 3= Mosque

7.4. Analysis of the First Pilot Model

Before starting the wind analysis, a study and simulation on small model of a room with dimensions (4x4x4m) was done. The aim of this step is to train on how to conduct analysis and simulation on the study area which draws many buildings. Wind pattern around building was studied as follows:

7.4.1. Preparation of 3-D model

Model for small building with dimension of 4x4x4m is prepared by using AutoCAD. The domain is defined by the dimensions (24x36x72) in line with the best practice guide lines, described in chapter four.

The model was saved in IGES file to be converted into the CFD Ansys.

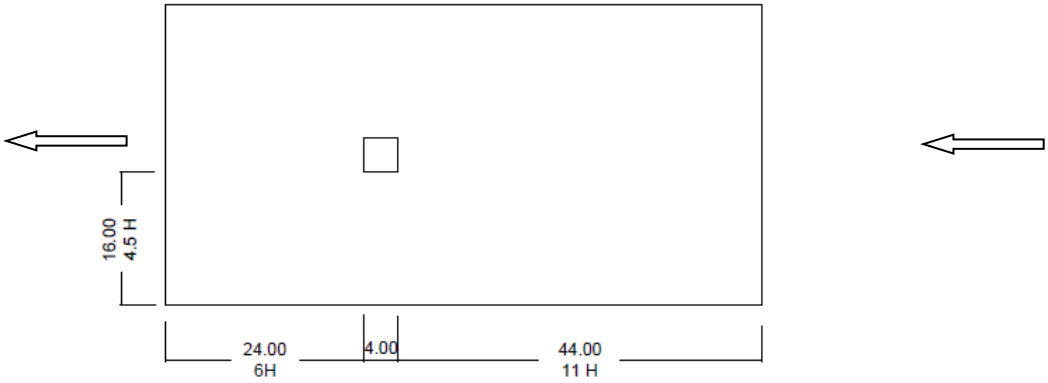

Figure7.4 model with dimensions 4x4x4 m. [Author]

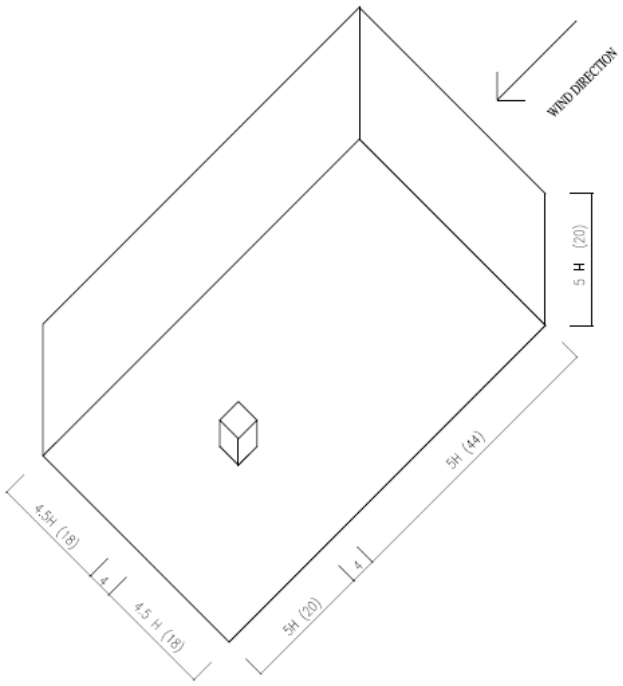

Figure7-5 Model and the surrounded domain. [Author]

7.4.2. Analysis and Simulation

3-D model was successfully entered in to CFD Ansys bench work version 6. The mesh with the dimensions of 0.5 units was chosen. The necessary variables were identified, where the wind speed is set to 6m/s, and the direction ranges from south to north. The mathematical equations are determined to be laminar equations as the wind movement is smooth and there is no turbulent wind.

The conditions surrounding the building were determined, so that there were no buildings around it. The air temperature was 35°c (average temperature in the study area).

Simulation and analysis process is conducted according to the above parameters. The analysis took an hour. The processing and analysis time is between one hour to several days, according to the size and the nature of the model, and the specifications of the computer used.

Although the process reached a solution and the wind pattern around mentioned model was analyzed, the results are unclear, and the wind pattern (speed, direction) around the model was not identified. Then the analysis and simulation process was carried out again as shown in figure7-6.

7.5 Wind Study and Analysis Second Pilot Model

Wind pattern around the model was analyzed as follows:

7.5.1 Preparation of 3-D model

The simulation was conducted on small building model by using Ansys CFD 16.

Using AutoCAD, a three-dimensional model with dimensions 4x4x4m was prepared. The dimensions of the computational domain are 88x44x24m. Figures (7.6, 7.7)

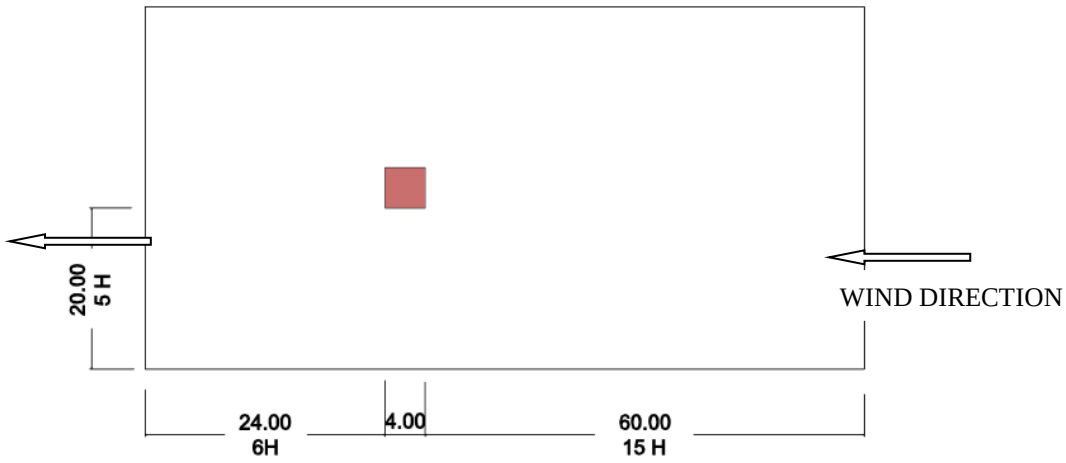

Figure 7.6 Model and the surrounded domain. [Author]

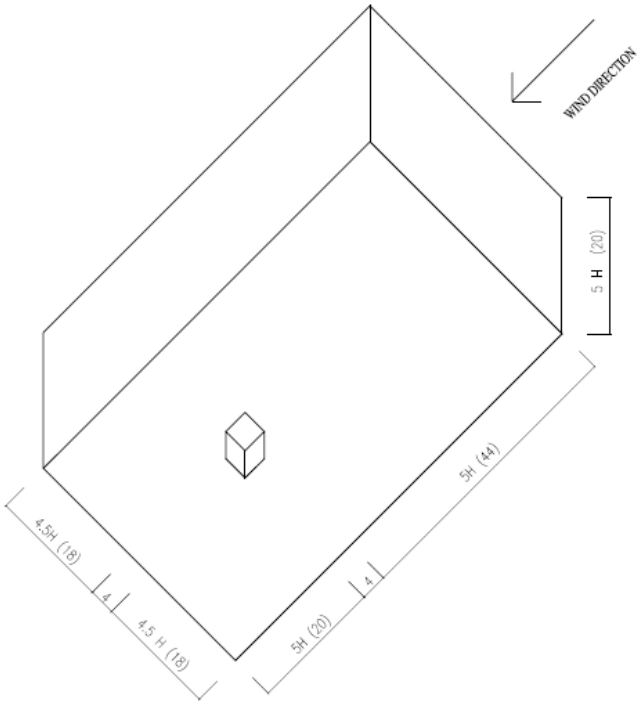

Figure 7.7 Model and the surrounded domain. [Author]

7.5.2. Analysis and Simulation

The model was analyzed twice. First, the grid mesh spacing was 0.5 unit and 0.1 unit respectively to see if there was a variation in the behavior of the wind speed and direction, why the results are unclear in the first model demonstrated in 7.5 above, and whether they are due to the mesh or other settings.

In the first time the grid dimensions were set to 0.5 and the number of items (cells) was 100.000. Then clear results and diagrams were obtained, showing the wind speed and direction around the building as shown in the following figures.(7-8, 7-9, 7-10).

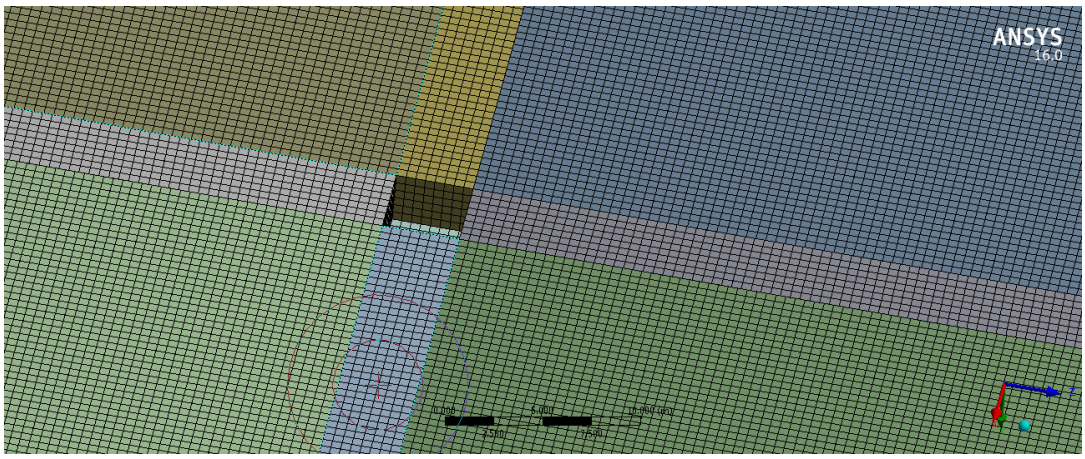

Figure 7.8 Mesh with dimensions of 0.5 units. [Author]

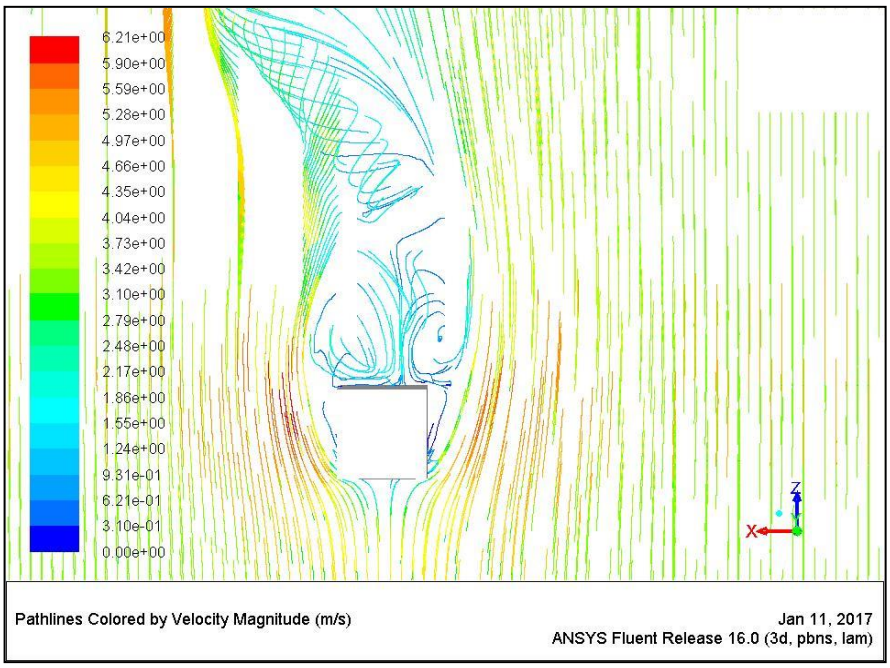

Figure 7.9 Wind pattern around the building (speed and direction) [Author]

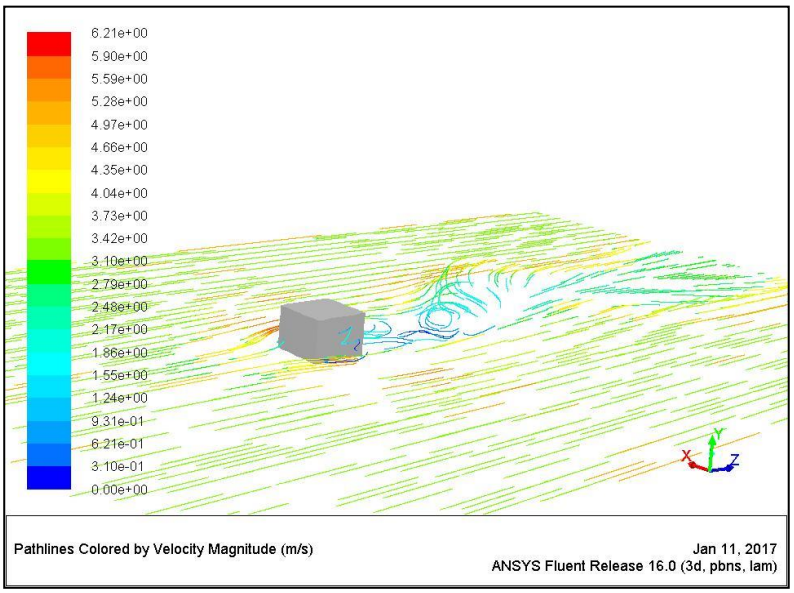

Figure 7-10. 3-D view for wind speed and direction. [Author]

7.5.3. The results

In figure (7-10), the colored lines represent wind speed and direction. At the, the red colour represents the average air velocity of 6m/s in the study area according to the information obtained from Meteorological Authority. The air is less rapid as we go down the yellow color. Then the green and the light blue show the great decline in air speed. The mysterious blue represents the static area, where the wind speed reaches zero.

The following points can be noted from figure (7-10):

1- Wind speed decreases between 1m/s to 1.5m/s when it collides with the building. There wind disperses to the top, bottom and to the two sides of the building.

2- Wind speed is lower in the adjacent parts of the building on both sides, while the speed increases as on both sides we move away from the building.

3- The vortexes area appears behind the building in the opposite direction of the wind, this area extends twice the building height. The wind speed in this area is between 1m/s to 2m/s.

4- Wind speed next the vortexes area is less than 1m/s to 2m/s and continues so for 48- metre distance (12 times the building height), then the wind returns back to where it was before the collision.

5- The effect of the building on lateral wind movement up to twice the width of building, Then it is observed that the wind passes in straight lines.

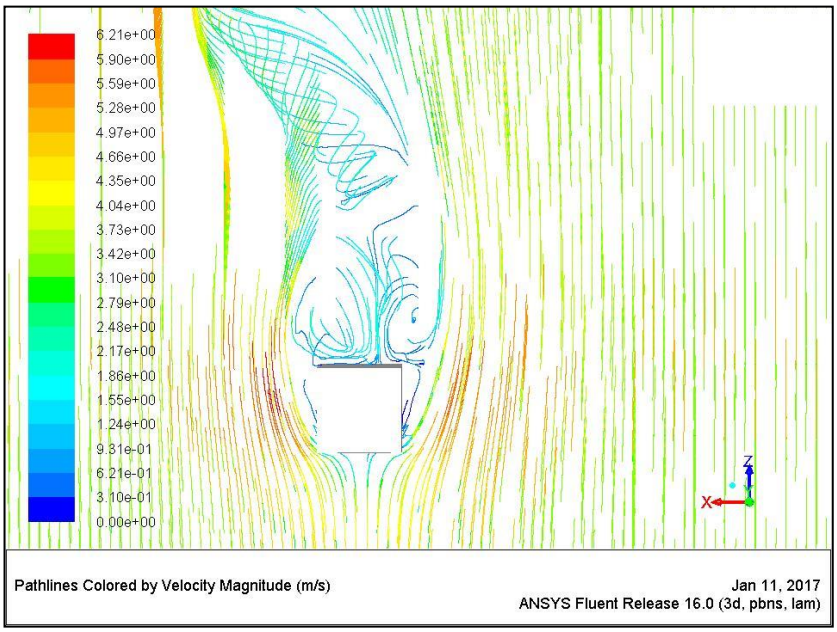

Figure 7.11 Speed and direction of the wind around the building (mesh 0.5). [Author]

When the model was analyzed by using mesh with dimensions of 0.1, the results shown in figure 7.12 bellow was obtained and the following facts were noticed:

1- Wind speed was reduced from 6m/s to 1.5m/s when it collided with the building.

2- An area with less air speed than 1m/s emerged on both sides of the building up to 1/3 of the building length which faces the wind direction, after this distance it gets faster between 5m/s to 5.5m/s until double length of the building. Then the speed becomes normal as before it collided with the building.

3- Vortexes appeared behind the building, and they continue so double the building height

4- Wind returns to its speed after 48m. (12 times the length of the building).

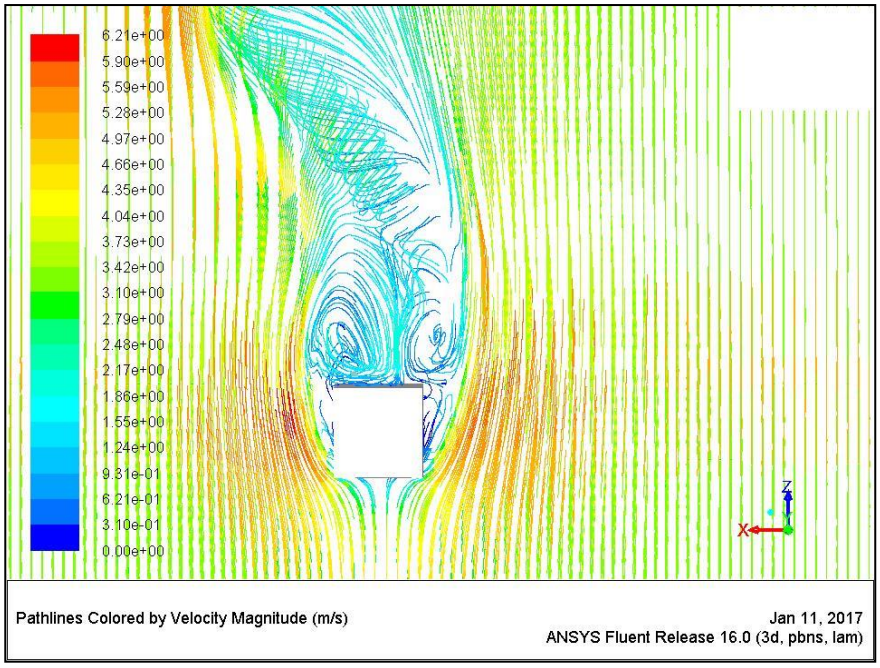

Figure 7.12 speed and direction of the wind around the building (mesh 0.1). [Author]

After analyzing this model, the following findings have been reached:

1- Incorrect mesh dimensions were the main cause behind the lack of clarity of the results as shown in model in (7.5) above.
2- The results of the two models (mesh 0.5 and 0.1) are identical. The only difference in the form of wind lines which is more clear and focused in the case of the mesh 0.1.
3- Accordingly, 0.1 distances for example is always chosen not only to have accurate results, but also to have a clear and more readable form.

7.6. Wind Analysis of the First Model

In the previous model, wind pattern around only one building was studied. There were no adjacent buildings affecting the wind and its speed around the model studied. In this model, wind pattern was analyzed and studied around a group of residential buildings, where the model was taken from the study area. The area consists of 12 houses. The area of each house is 400 m2 (20x20m). Each house has a built up area between 150 m2 to 200m2. It has internal yard in the front and the back, and corridors on both sides. There is a 2- meter high wall separating neighbours. This type of residential planning is predominant in the

Sudan. The heights of the buildings vary from one-storey (4m) to four stories (13m) (the maximum height allowed in third class neighborhood.

In this case the model was directed to the south- north direction. This is also the predominant pattern in the residential neighborhoods of Sudan, where two rows of attached houses to the boundary wall are placed. The first row is placed in the south direction, while the other one is directed to the north. The two directions are preferred to ensure natural ventilation.

The study aims at examining the movement and direction of the air in the inner yards to investigate the effect of the south- bound houses on those heading north and vice versa.

In addition, the study aims also at finding out the adequate space between two houses to provide natural ventilation to each one.

Figure7.13.Aerial view of the study area [Author]

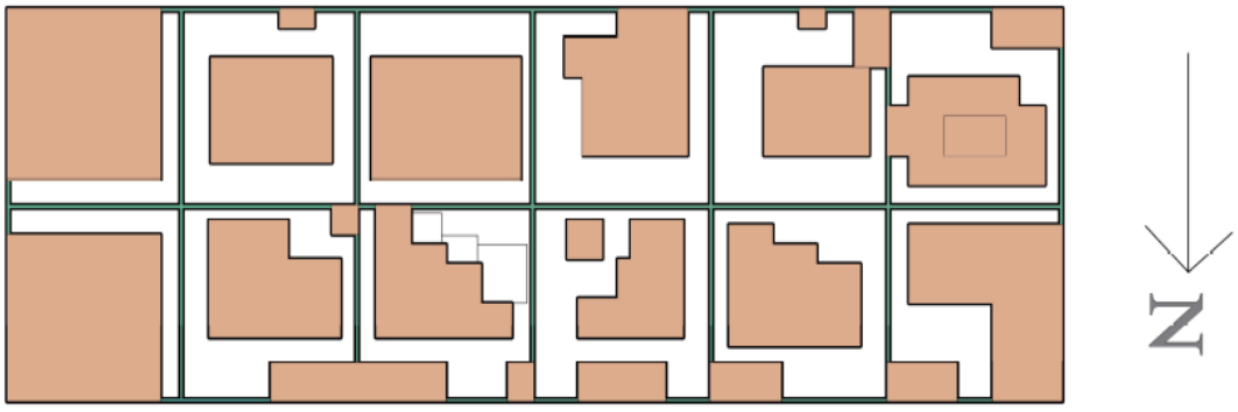

Figure 7.14.Plan of the model [Author]

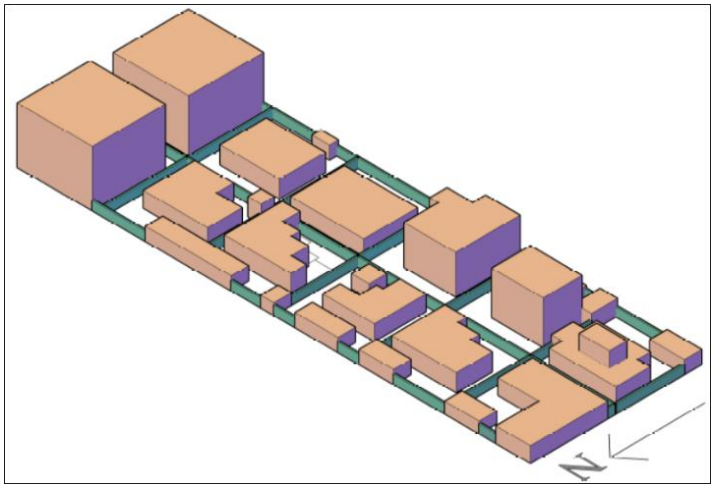

Figure 7.15.Three dimension of the model [Author]

7.6.1. Modeling for computational Simulation

Model was prepared by using Auto CAD, and then it is converted and inserted into Ansys 16 CFD, to study the behavior of the wind around buildings. Figure 7.15

7.6.2 Computational Domain and Grid

According to the best practice guideline highlighted in chapter four, the computational domain is specified with the dimension of 240x292x72. See (figure 7.16)

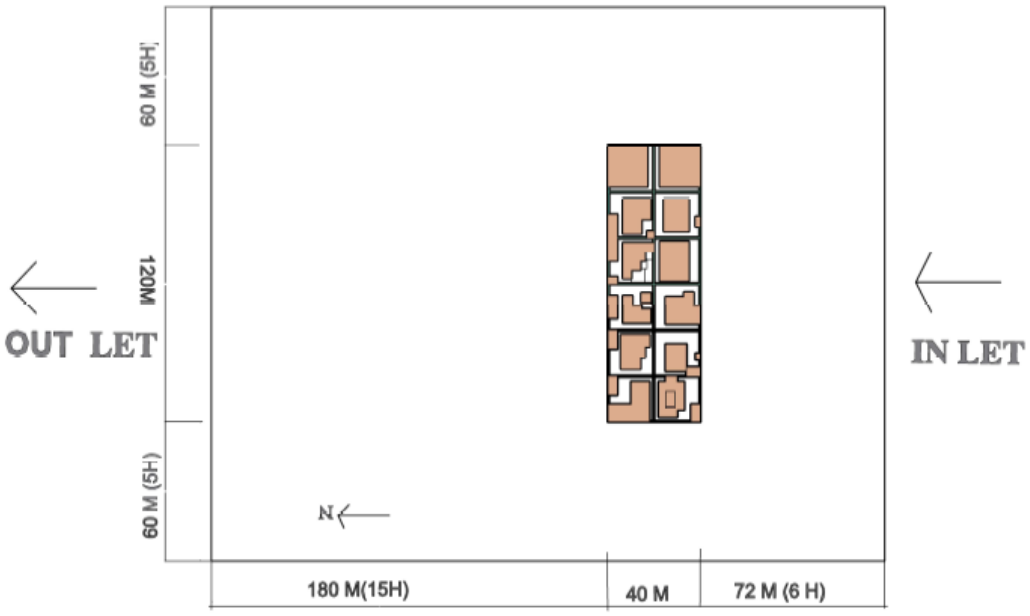

Figure 7.16. Computational domain [Author]

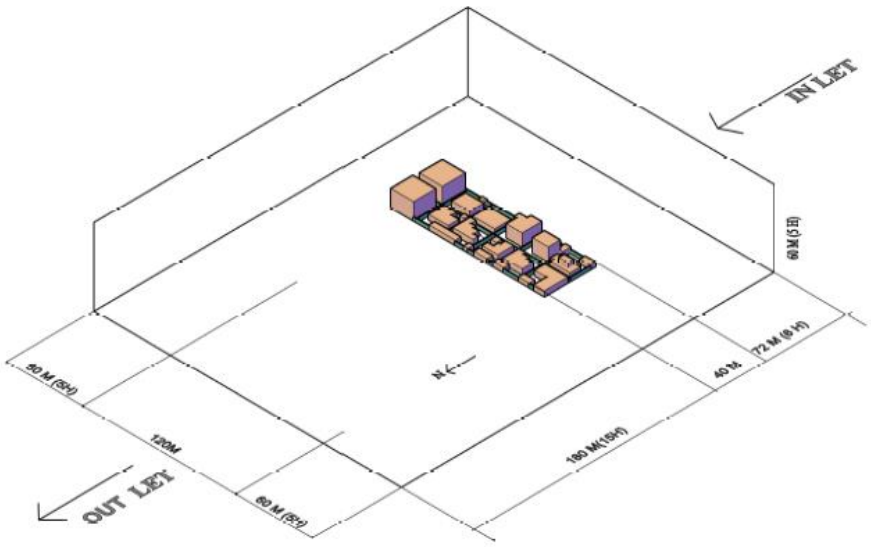

Figure 7.17. 3 D model and the surrounded domain [Author]

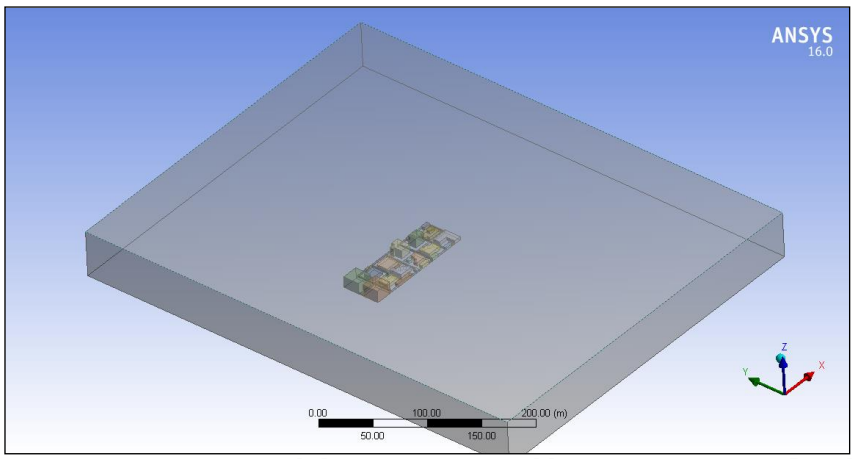

Figure 7.18. Computational domain generated by Ansys 16 CFD [Author]

The short side of the model is oriented to east and west directions, while the long side is set to the north and south. This will help study the behavior of wind in this situation and know the accessibility of air to all the buildings for natural ventilation purpose. See Figure (7-14).

Complex mathematical equations called continuity equations and NAVIR-STOCK are used to calculate the wind speed and behavior at any point after colliding with a group of buildings. It is known that these equations are hard to solve, and some are unsolvable, so the CFD software is designed to simulate and study the air movement. This software uses the mesh (grid), rather than mathematical equations.

In this model, the Navir – Stock equation was used because the wind does not have vortex.

There are several types of mesh used in the CFD software: Tetrahedral (Tet), Pyramid arbitrary, Polyhedron, Hexahedron (hex). In this model, the Tetrahedron mesh (grid) was used. The total number of the items (cells) is about 5,391,427 after the model was split in to a mesh (grid) figure (7-17).

Wind speed was determined at the domain inlet by 6m/s. the average velocity in the study area. The wind direction is north to south, while the pressure equals zero at the exit. The upper surfaces of the domain, as well as the side surfaces, are considered as free walls, the floor and building roofs are considered as soft walls and represent the urban environment.

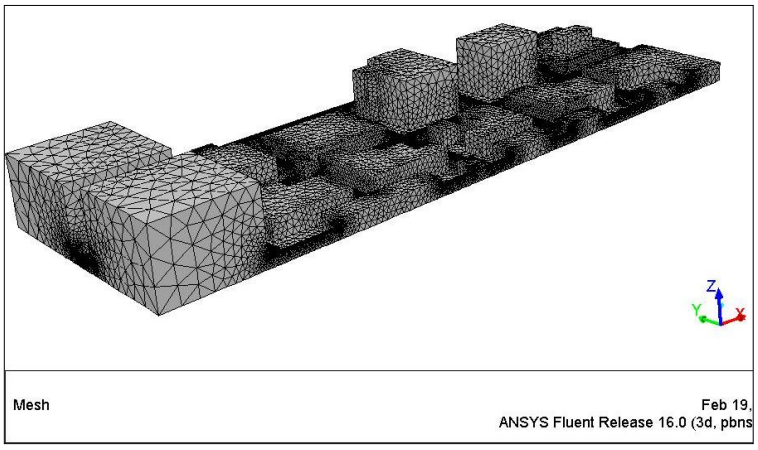

Figure7.19 3D Tetrahedran mesh generated by Ansys 16 software. [Author].

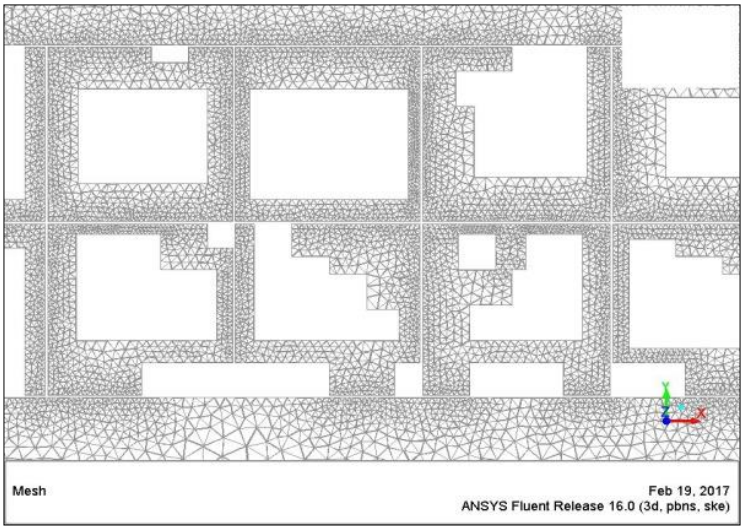

Figure7.20 2D Tetrahedran mesh generated by Ansys 16 software. [Author].

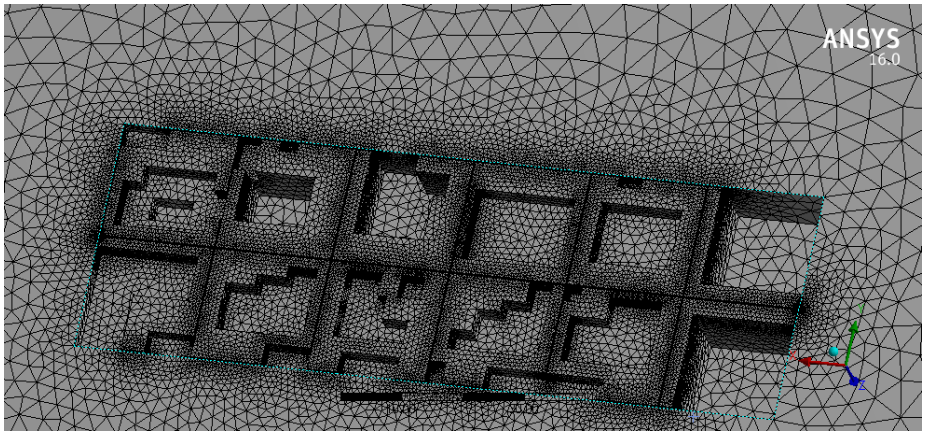

Figure7.21 2D shows Tetrahedran mesh generated by Ansys 16 software. [Author].

7.6.3. Analysis and Simulation by CFD

Only two houses have putt in direction where wind blow. One is opened to north and other to south. This is the common planning of most residential areas in Sudan. Wind speed and direction were read at height of 1m, 1.5m, 4.5m, 7m, and 10m. The height of 1m and 1.5m is equal to the level of the windows of the ground floor, the height of 4.5 m is at the same level of the windows on the first floor, the height of 7m is regarded as higher than the level of the two-story building and the windows, while the height of 10m is equal to the windows level of the third floor.

7.6.4. Result Analysis

7.6.4.1. Wind Pattern at 1m and 1.5m Level

1- At these heights, the wind speed at the beginning of the residential area ranged between 2.9m/s to 3.7m/s.

2- Speed dropped to1.7m/s in the side corridor after 20m from the beginning of the residential area and then less speed up to 1.2m/s at 30 m after beginning of the residential area.

3- On the opposite side of the wind direction, the speed is less than 1m/s. Vortexes appeared here and the wind scattered in all directions, Figures (7-22, 7-23, 7.24, and 7.25).

4- Wind pattern at 1.5m height is not different from that at the height of 1m, Figures (7.24, 7.25).

5- There are vortexes in the inner courtyard of the houses, and the wind in these courtyard moves in different directions with speed ranging between 0.5m/s to 0.8m/s

Wind direction changes from north to west and also to east, when it collides with boundary wall which separates houses or collides with a building in the direction of the wind.

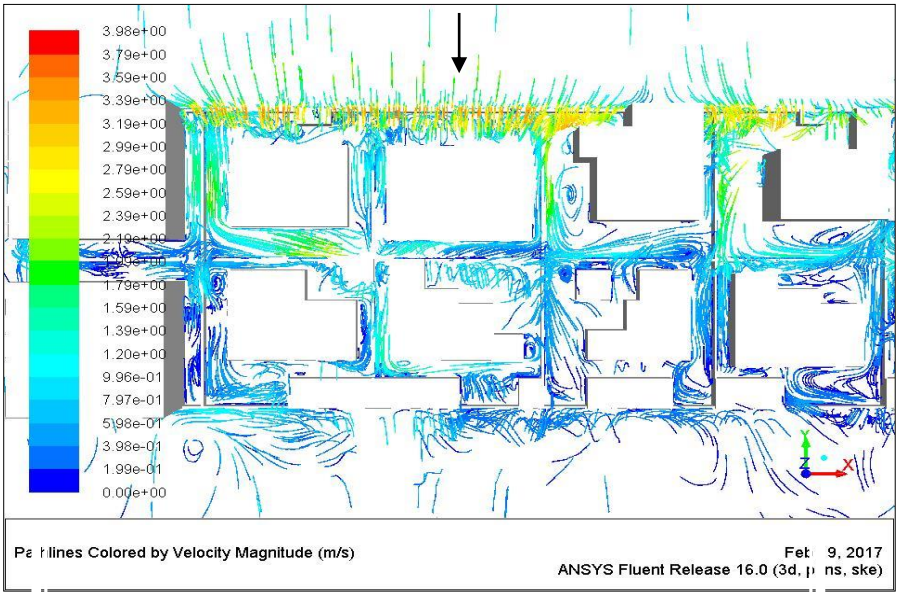

Figure7.22 Wind pattern around buildings at 1m.

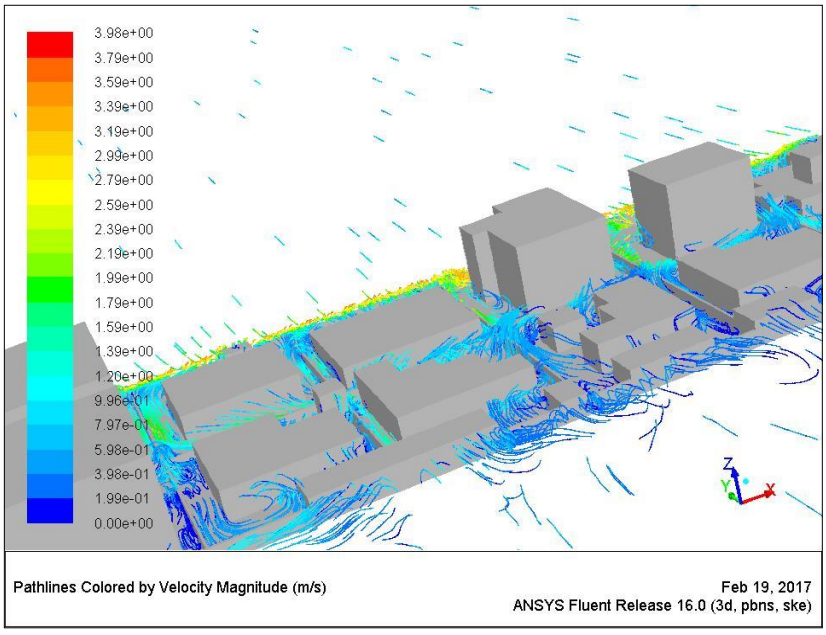

Figure7.23 Wind pattern around buildings at 1m. [Author]

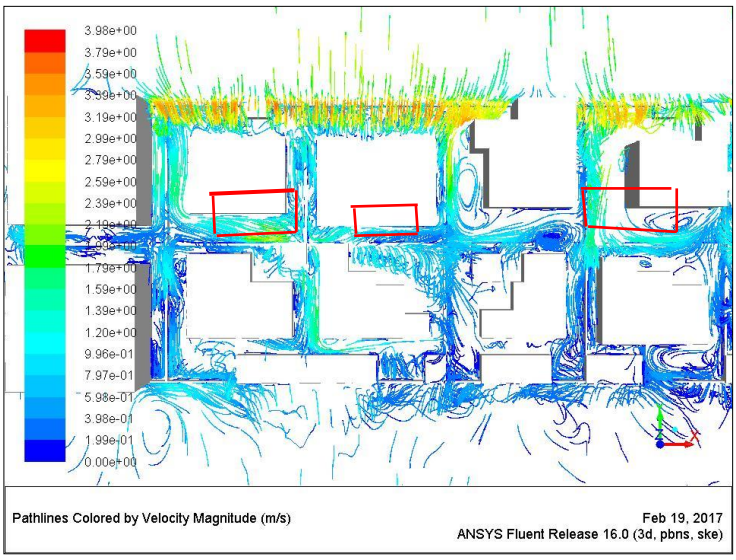

Figure7.24 Wind pattern around buildings at 1.5m. [Author]

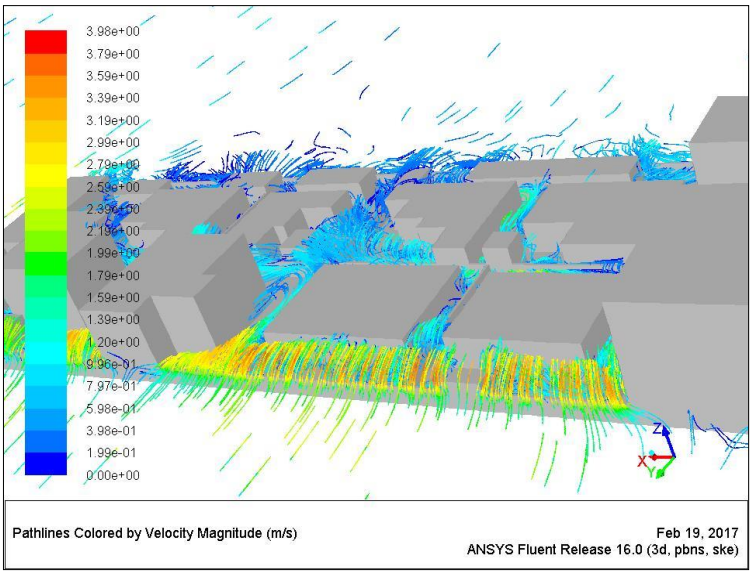

Figure7.25 wind pattern around buildings at 1.5 m.

7.6.4.2. Wind Pattern at 4.5m

1-At this height, the wind speed increases in the area between two high buildings, reaching between 3.7m/s and 3m/s. However, the velocity decreases after 10 meter because the building intercepts the wind path. Figure (7.26), the area specified in the red rectangle.

2- Speed of wind increases above the building with a height of 4.5 m. There are vortexes in the same places where the vortexes appeared at height of 1.5m.

3-Speed around buildings ranges between 1.5m/s to 3.5m/s.

4-Wind speed in internal courtyards ranges between 2m/s to 3m/s.

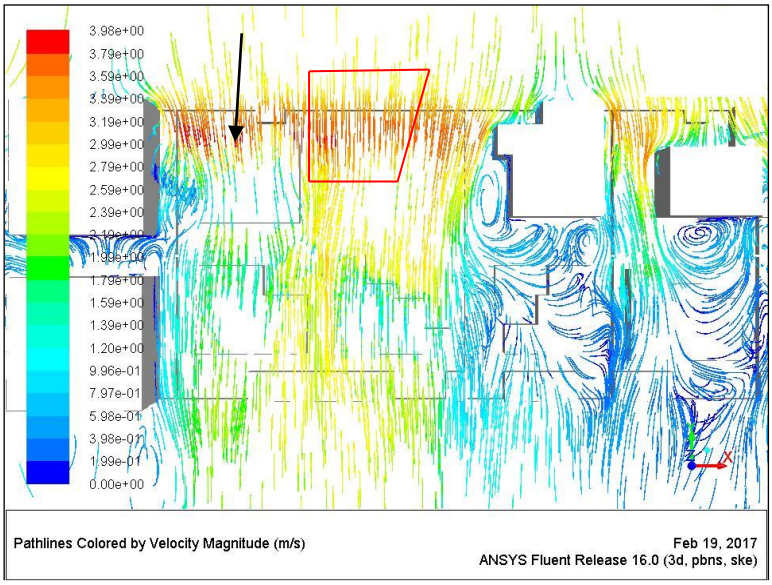

Figure7.26 Wind pattern around buildings at a height of 4.5 m.

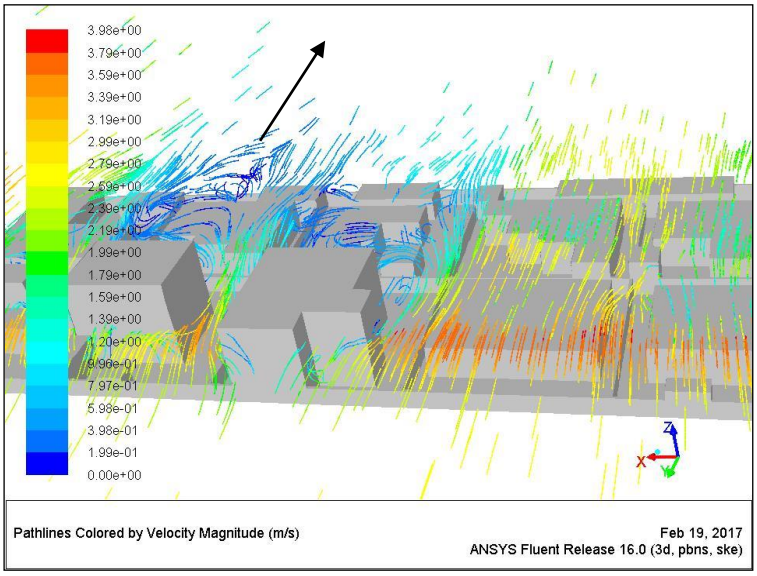

Figure7.27 Wind pattern around buildings at a height of 4.5

7.6.4.3. Wind pattern at 7.5 m

According to the figures (7.28, 7.29) the following points can be noticed:

1-Wind speed increases to reach 3m/s and changes its direction upward when it collides with building up to 3m and 4.5m, and all buildings below 7 meters.

2-Wind speed increases to 5 m/s, in the area between buildings with a height of more than 7 m.

3-The vortexes occur, and the wind speed decreases to 1 m/s behind buildings over 7 meters.

4-The internal boundary wall between houses does not affect the movement of wind.

5-Wind speed around tall buildings (3 stories) ranges between 1.5m/s and 3m/s.

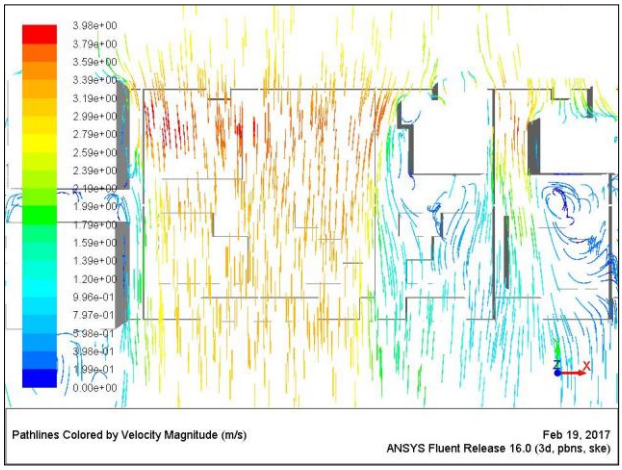

Figure7.28 Wind pattern around buildings at a height of 7.5 m. [Author].

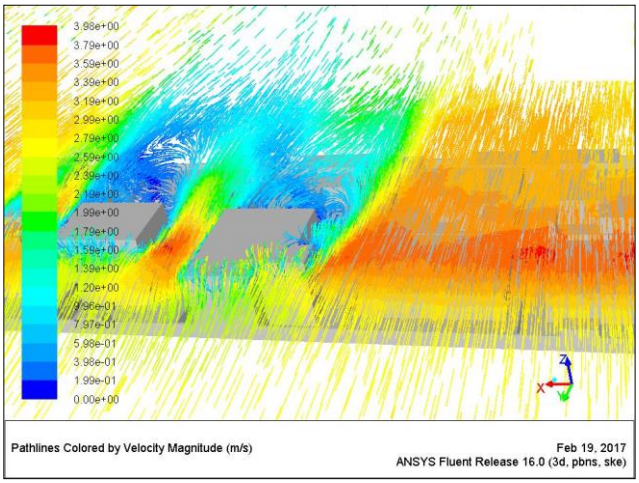

Figure 7.29 Wind pattern around buildings at a height of 7.5 m. [Author].

7.6.4.4. Wind pattern at 10.5 m

At this height, it is noticed that the wind speed above the building with one storey (4m) or two (7m) ranges 3.4 m/s to 4.5 m/s, higher than the speed in the same area. At the height of 1m and 1.5m the speed ranges between 2.9m/s to 3.7 m/s. It can be noted that the wind speed above this is less. The wind direction at a height 10 m starts regularly towards north, and there are no vortexes or change in direction, as in lower heights. Figures (7.30, 7.31)

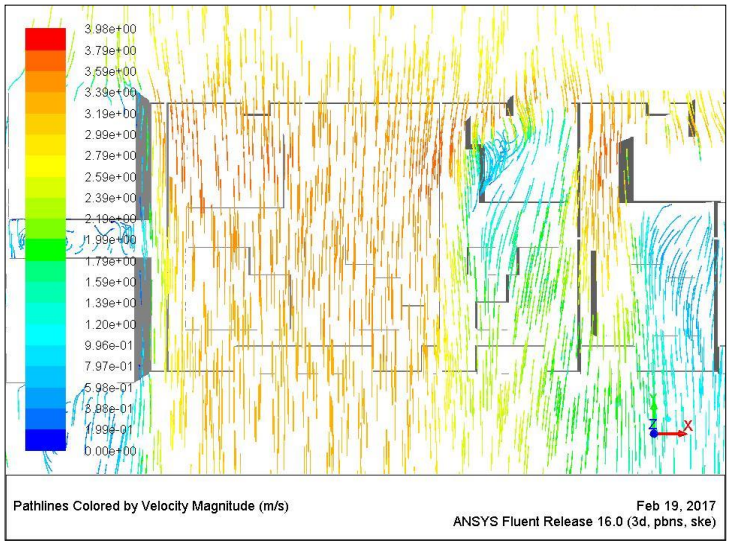

Figure 7.30 Wind pattern around buildings at a height of 10.5 m. [Author].

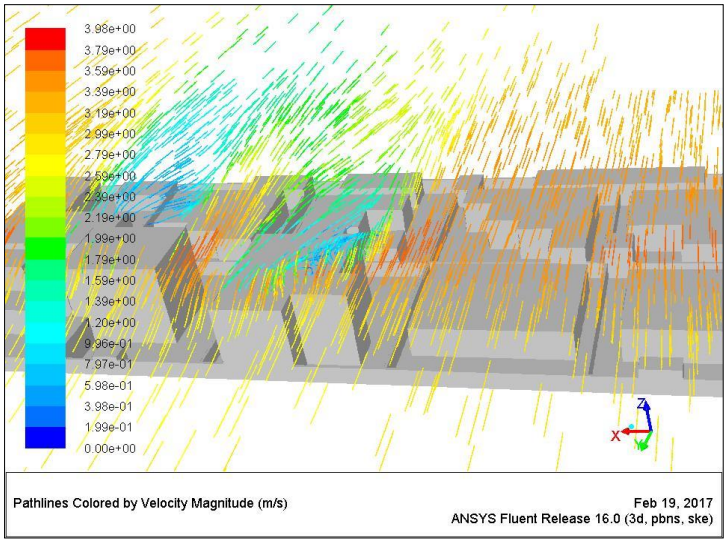

Figure 7.31 shows the wind pattern around buildings at a height of 10.5 m. [Author].

7.7 Analysis of the Wind Pattern of Second model

7.7.1 Model Description

The model is taken from a third class residential area. This model represents the existing situation of the study area. The total area of the model is 244,420 m2 with the dimensions of 505x484 m. The model consists of 242 houses (400 m2 of each house), a mosque, two schools and open spaces of varying areas for different public activities. Figures (7.1, 7.32, 7.33)

The heights of the buildings in this area vary from one (4m) to four stories (13). This is the maximum height allowed in third class neighborhood. Figure 7.33

The area is planned and built according to urban planning law in Khartoum State.

There are boundary walls separating house. Each house consists of a built up area and a court- yard, and sometimes there are two internal courtyards, one is at front of the building, while the other at the back.

Some houses are oriented north and the other to the south. Other are oriented east or west.

There are streets in the north and south direction of the block and the other in the east-west directions. The width of the streets 15 meters, and there are open spaces with different areas for different activities.

7.7.2.3D Modeling of Simulation

A three-dimension model of the residential area is prepared with Auto CAD, as in figure (7.33). Then it is converted to Ansys 16, to conduct wind speed and pattern analysis around buildings, streets and open spaces.

Figure 7.32 . Plan of the second model. [Author].

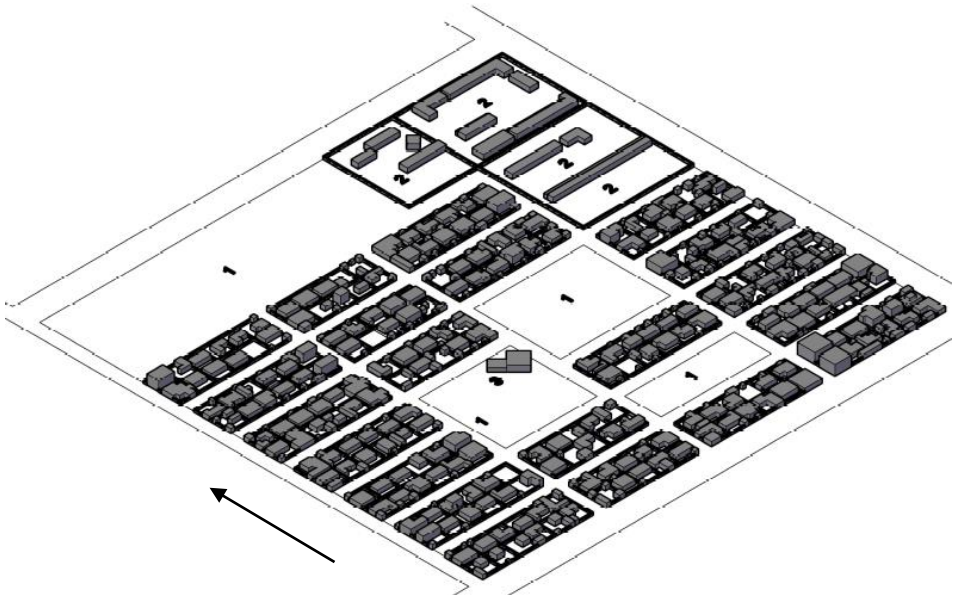

Figure7.33 Three D for the second model. [Author]

1= Open space, 2 = School, 3 = Mosque

7.7.3. Computational domain and mesh

the simulation is done within the urban area which contains of 242 houses, including the court yards, the streets surroundings, and the open spaces, the model is defined by a calculation domain with size of 694m, 613m and 65 meters in directions x,y and z, respectively. Figure (7.34).

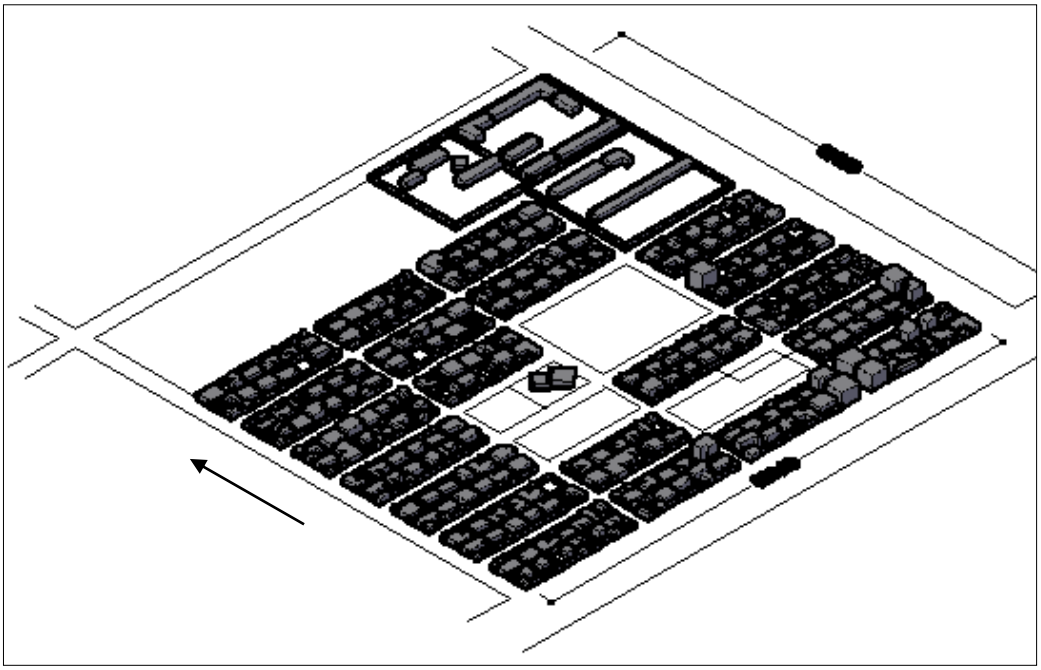

Figure7.34 Three D for the second model.

7.7.4. Using CFD for simulation and analysis

In this model, the wind pattern is analyzed and studied within the residential area, to investigate the behavior, speed and direction of the wind, the effect of buildings, boundary walls which separate the houses and inner courtyards on the speed and direction of the wind.

Ansys CFD 16 is used for analysis of the wind speed of 6m/s, and north east as predominant direction. Navir-Stock equations were used in the analysis process. Readings is performed at different height starting at 1m and up to 10 m, the highest points in the study area. (Level of windows equal to 3rd floor).

7.7.5. Results Analysis

Wind pattern at different levels within the residential area is analyzed as follows:

7.7.5.1. Wind Pattern at 1.5 m Height

Path lines and direction of the wind is shown in figure (7.35), while the speed of wind shown is in figure (7.36) in the residential area. The wind speed is highlighted as the red and light red, yellow, green, then the light blue and mysterious blue.

At this height the following results are reached:

1- Wind speed varies between 2.5m/s and 2.8m/s when it collides with the buildings.
2- Speed decreases in the first row (highlighted by the red square). The speed ranges between 1.7m and 2 m/s.
3- Speed drops further in the buildings which follow the first row. It varies between 0.5 and zero m/s. This means that the wind speed is much lower in the inner courtyard of the houses.
4- It is noted that the wind speed in the side corridors of the buildings ranges between 0.5m/s to 1m/s and higher than the speed in the courtyard behind the houses, which ranges between 0.0m/s to 0.5m/s. Figure (7.35)

5- The wind speed in the streets heading in the same direction of the wind route is greater than the speed within the houses. The speed varying between 3ms and 4m/s increases in these streets. See figures (7.35, 7.36)

6- In open spaces, the wind speed is slightly lower than the speed at the beginning of the residential area. The speed ranges between 1 m/s to 3.5m/s.

7- Wind speed in the houses which are located next to the squares is faster than those located before squares. The speed varies between 1.7m/s and 3.5 m/s. Then, the speed drops within the houses. Figure (7.35)

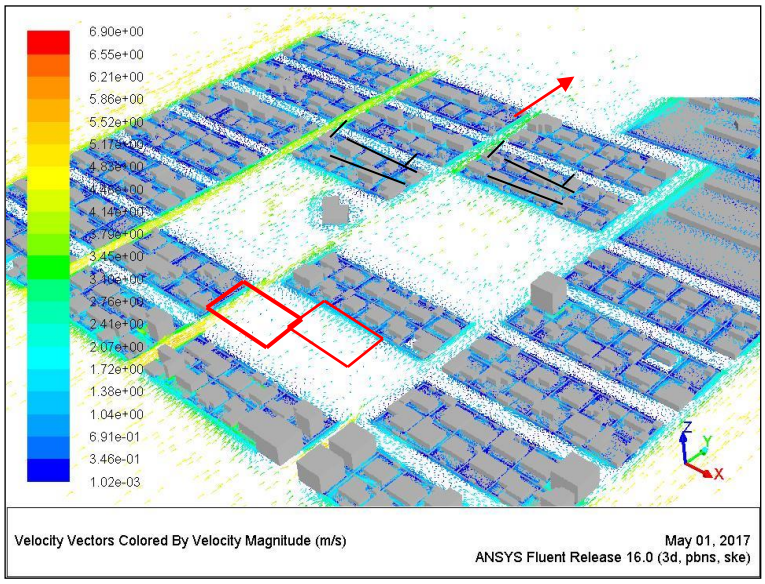

Figure7.35 Wind speed around buildings at 1.5m. [Author]

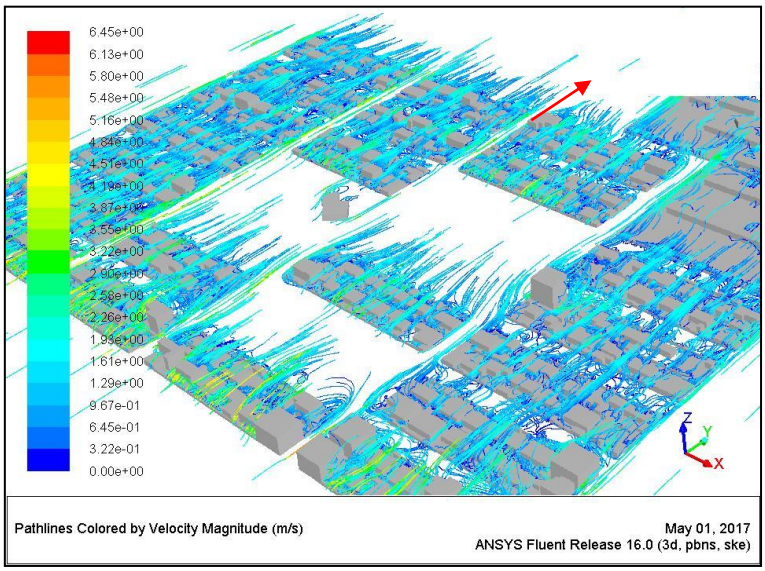

Figure 7.36 Wind paths through buildings at 1.5m. [Author]

8- Wind speed in the street heading west-east is less than 1m/s because the row of houses intercepts its path. This results in change of direction. The street width is 15 m. figure (7.37)

9- It is clear that the wind direction in the parts highlighted in the red frame is directed toward the east and west, although the real direction of the air is north south. See figure (7.37). The wind speed in north-south street ranging between 3m/s and 4m/s and is higher than the speed of the wind in the street heading east and west.

10- It is noticeable that the wind speed ranges from 2.4 to 2.7m/s within inner courtyards of the two – story buildings near the north- south streets. The speed in the inner courtyards of one-story buildings reaches 1.7 m/s and less than 1 m/s.

11- The vortex is clear behind the walls and the buildings which intercepted the wind route and the inner courtyards.

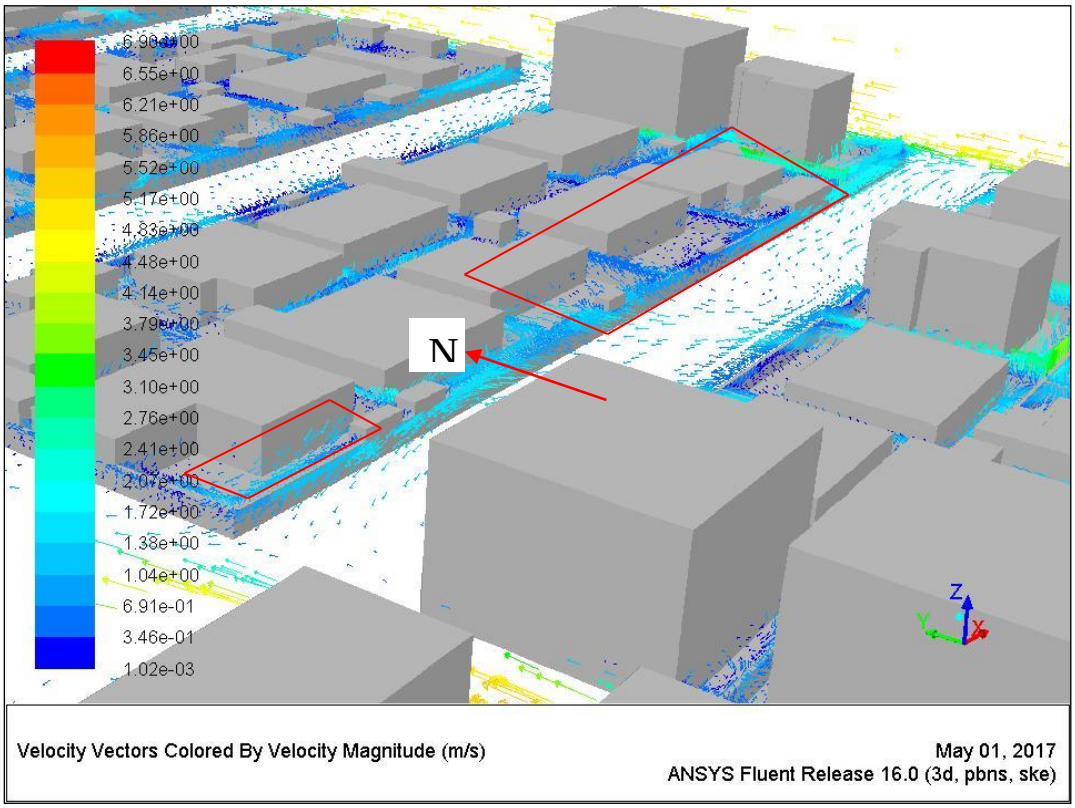

Figure 7.37. Wind direction in the east and west streets, [Author]

7.7.5.2. Wind Pattern at 4.5m Height

At a height of 4 m, it is obvious that the wind speed at all points within the residential area is higher than its speed at height of 2m. The speed varies between 1.5m/s to 5.5m/s at different points as follows:

1- Speed at the beginning of the houses ranged between 2.5 m/s to 6 m/s.
2- Speed decreased within the houses ranging between, 1.0 m/s to 2.0 m/s.
3- Speed and direction of the wind is affected by the heights of buildings, as the speed drops behind the high buildings (three stories) and ranged between 3.5 m/s to 1.2 m/s, The vortexes appeared in different directions behind it. The speed fell from 3.5 m/s to 3 m/s behind the one-storey buildings.
4- Wind speed at open space with 70 m width and which is located next the houses varies from point to another point according to the height of the buildings behind it. It is generally ranges between 1.5m/s and 2.5m/s.
5- Wind speed increases noticeably from 1.5 m/s behind the buildings to 3.5 m/s after crossing the open space which is 100 m wide.

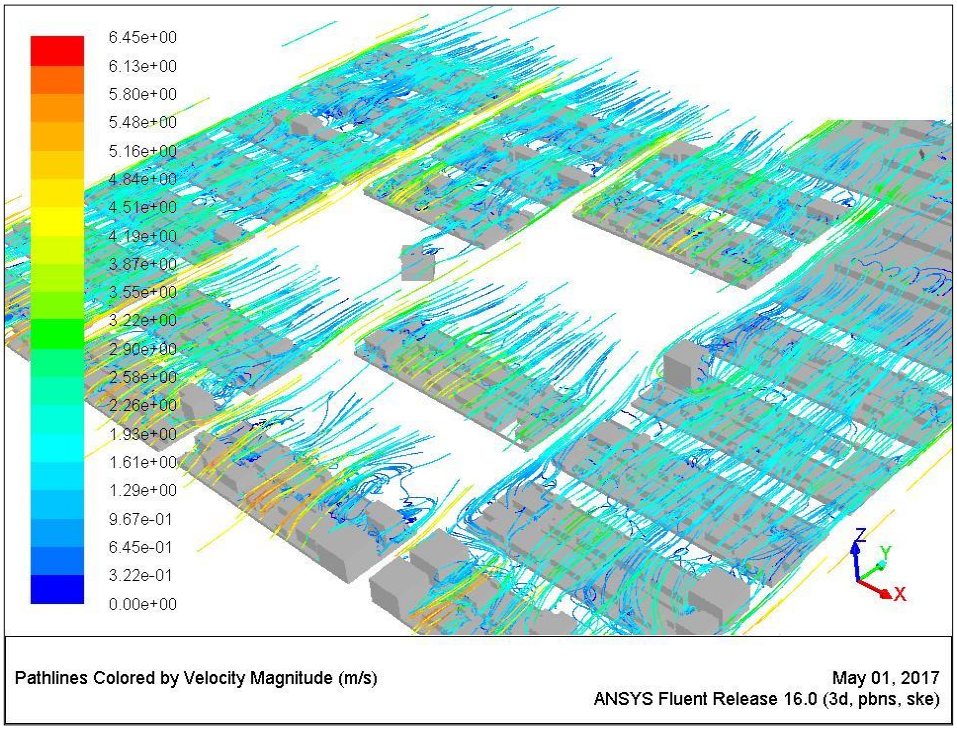

Figure 7.38 Wind speed around buildings at 4.5m. [Author]

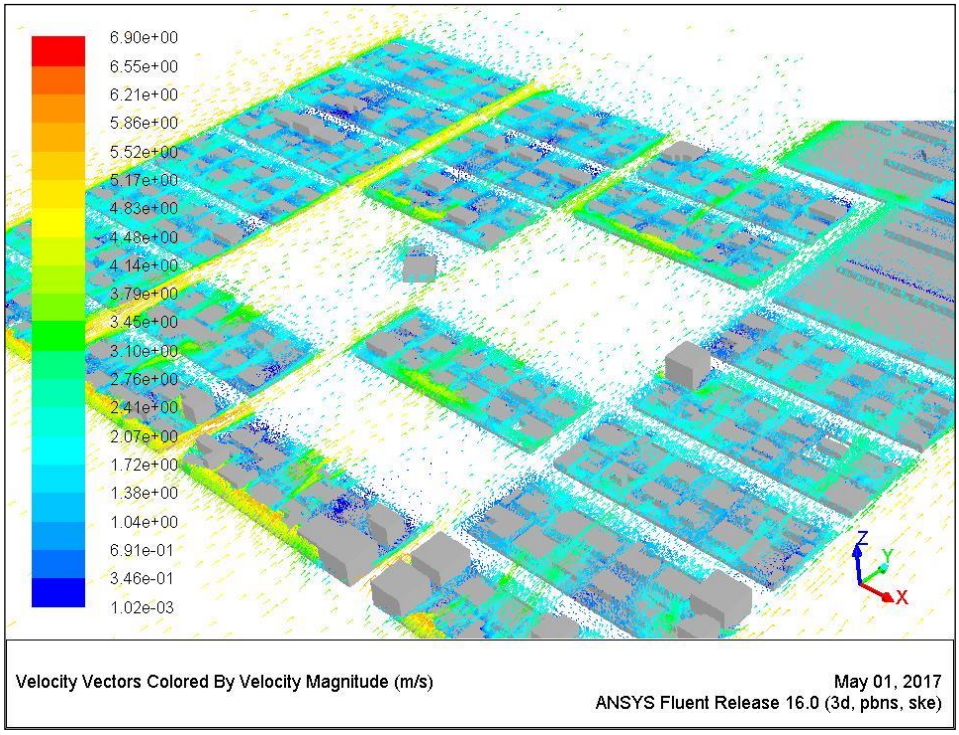

Figure 7.39 Wind path lines around buildings at 4.5m. [Author]

6- It is clear that the wind speed at 4.5 m height ranges between 2.7m/s to 3.5m/s higher than 1.5m height which ranges between 1m/s to 2m/s. figure (7-40),

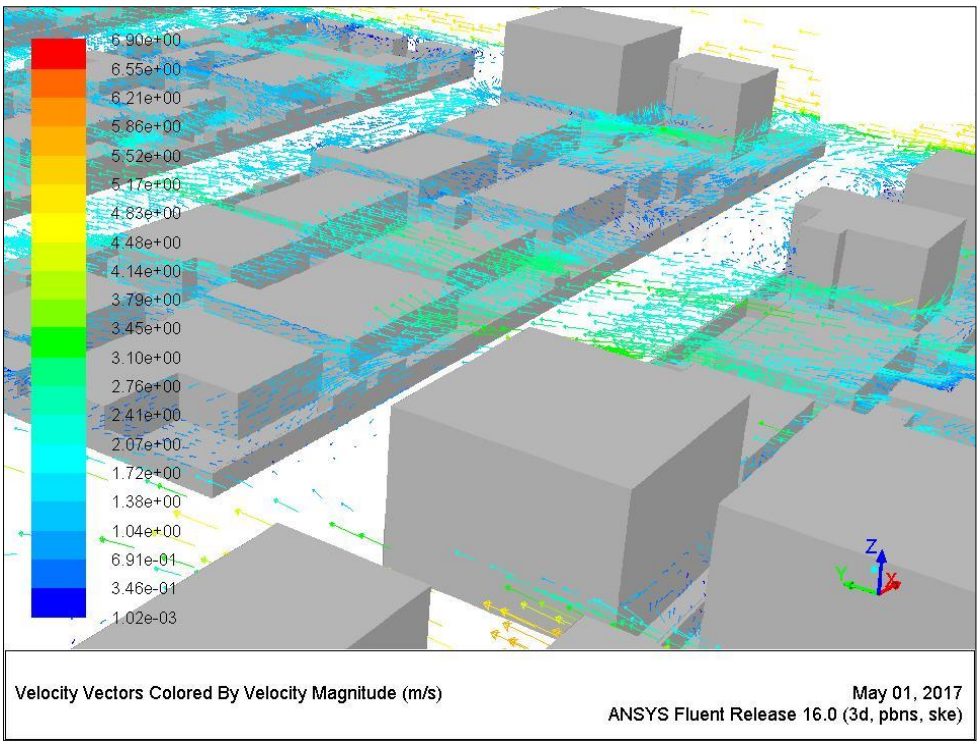

Figure 7-40 Wind path lines and speed around buildings at 4.5m. [Author]

7.7.5.3. Wind pattern at a height 7.5 m

At a height of 7.5 m, it is clear that the wind speed ranges from 2.5 m/s to 5.5 m/s, i.e. it is higher than the speed at 4.5 m.

Also the first row of houses affects the following rows of houses as follows:

1- The first row of one-story houses has no effect on the rows of the next houses, and the wind speed over these houses is 5 m/s. See the houses highlighted in red frame. Figure (7-41, 42).

2- The first row of high buildings (three-story) affects less high buildings (one story), where the air speed above the lower houses is 2.5 m/s compared to its speed when it collides with tall houses (5 m/s). Look at the houses inside the black frame in the figures (7-42) and (7-43).

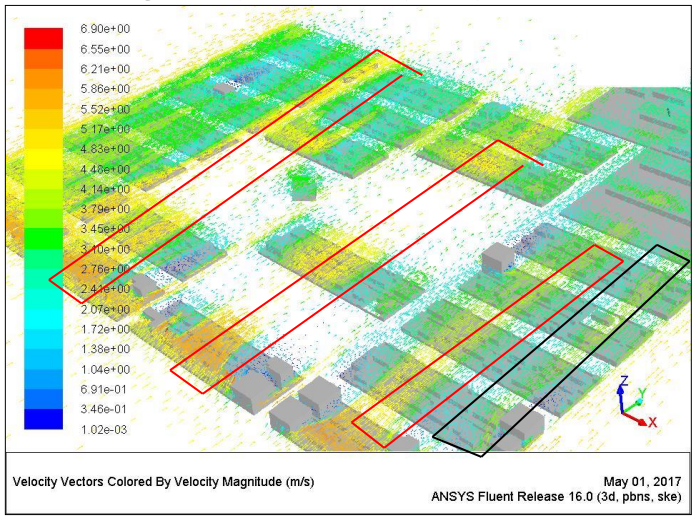

Figure 7.41 Wind speed around buildings 7.5 m. [Author]

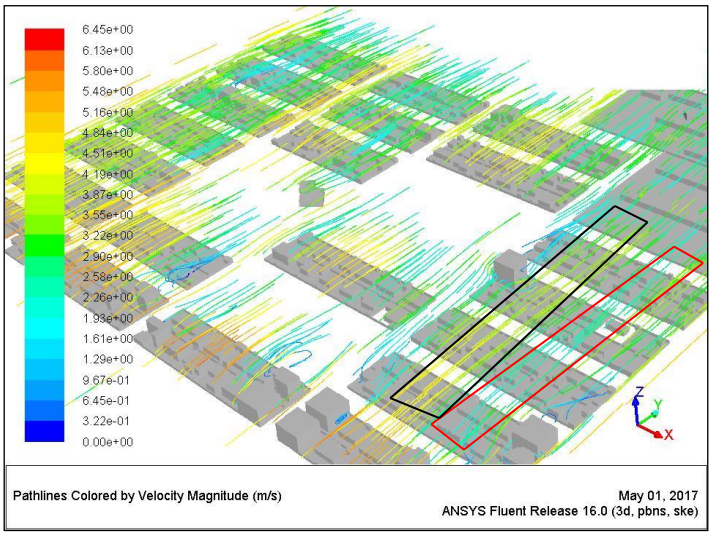

Figure 7.42 Wind path lines around buildings at 7.5m. [Author]

3- The wind keeps its path and velocity when it crosses the open spaces. The wind is not affected by houses under its path. See the air path 1 in the Figure (7-43).
4- Wind speed at this height equal to 5 m/s before colliding with houses, then the speed drops between 3m/s and 4 m/s when it collides the boundary wall. See figure (7-43) frame 1.
5- After colliding with the boundary wall, the wind changes its direction upward, colliding with the houses which are located behind the boundary wall, then the wind speed increases over these houses until it reaches 5.8 m/s, as in figure (7-44) frame 2.
6- When the wind passes these houses, the speed drops slightly to 5.2 m/s, as in figure (7-43), frame 3. The air passes at this speed above the open space with 70 m wide, and then it collides with the houses which are located next the open space. The speed above these houses decreases to 4.4 m/s. See figure (7-43) frame 4.
7- It is clearly that the wind speed above the houses located behind high houses is less than the speed above the houses situated behind the low houses. figure (7-44),

7.7.5.4. Wind Pattern at 10.5m Height

At 10 m height above the residential area, the following points are noticed:

1- Wind speed in the beginning of the residential area is not different from it is velocity above the houses.
2- The wind speed drops to 3m/s above the houses located beyond tallest houses.
3- The wind speed drops to 3 m/s in the areas located between tall houses.
4- There is no difference between air speed in the streets and within houses. Figure 7.44

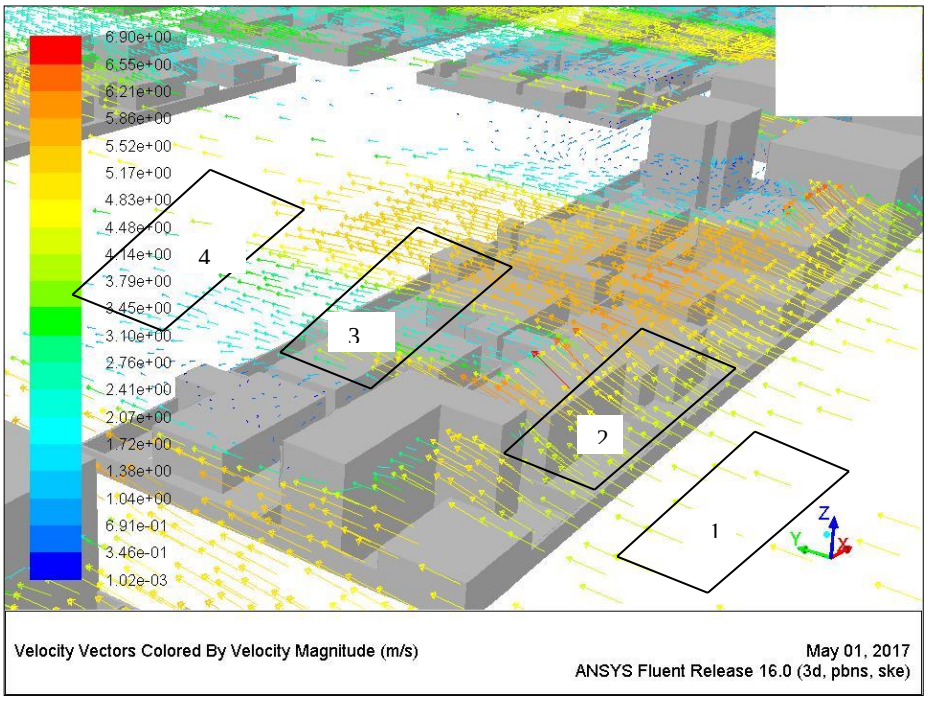

Figure 7.43.Wind path lines around buildings at height 10.5 m. [Author].

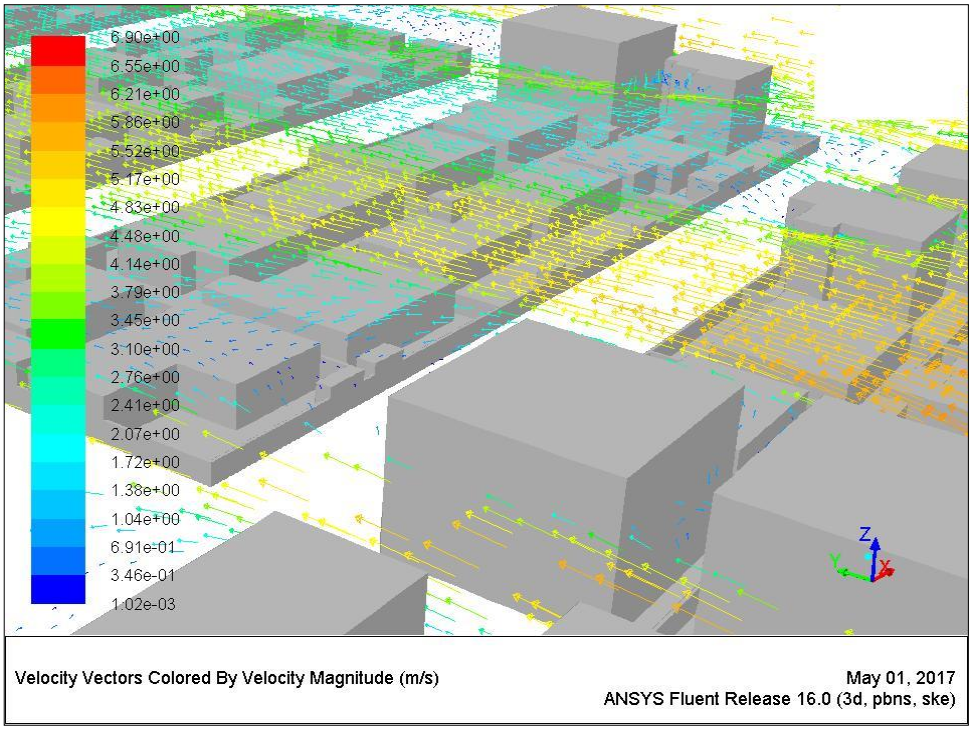

Figure 7.44 Wind path lines around buildings at height 10.5 m. [Author]

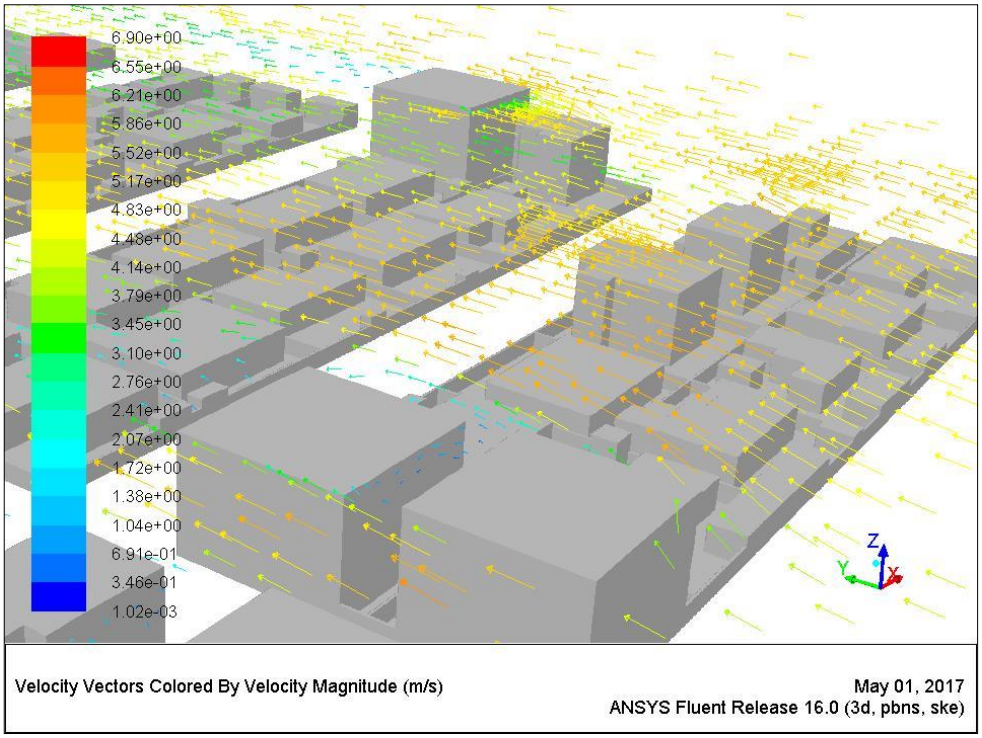

Figure 7.45 Wind path lines around buildings at height 10.5 m. [Author]

7.8. Analysis of Wind Pattern of the Third Model

7.8.1. The Model Description

This model is based on the hypothesis that all houses are of same height 4 story (13m), The total area of the model is 244,420 m2 with the dimensions of 505x484 m. The model consists of 242 houses, (the total area per house is 400 m2), one mosque, two schools and public spaces with different areas for community gathering. Figures 7.46

The heights of the houses are equal to four-storey (13m)). This is the maximum height allowed in third class neighborhood. Figure 7.46

There are boundary walls separating houses. Each house consists of a built up area and a court yard. Sometimes, there are two internal courtyards: one is at front of the building, while the other at the back.

Some houses are oriented north and the other south. There are streets in the north and south direction of the block. Other streets are located in east-west directions. The width of the street is 15 meters. There are public spaces of different areas for different activities.

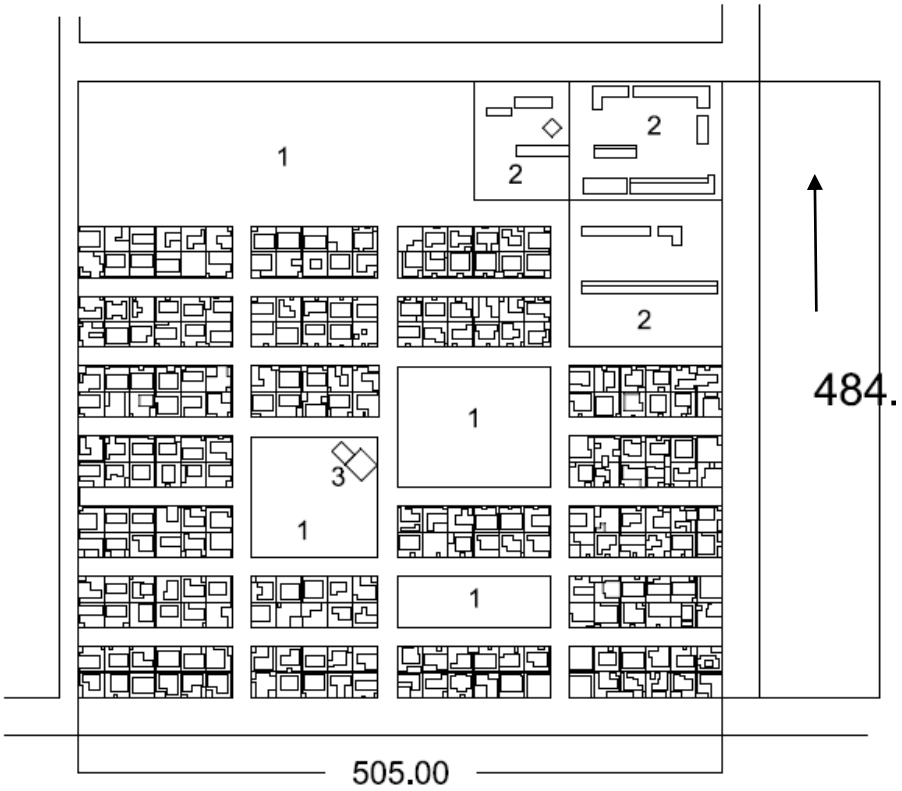

Figure 7.46 Plan for third model (all houses with four storey, 13m). [Author]

1= open space, 2= school, 3= mosque

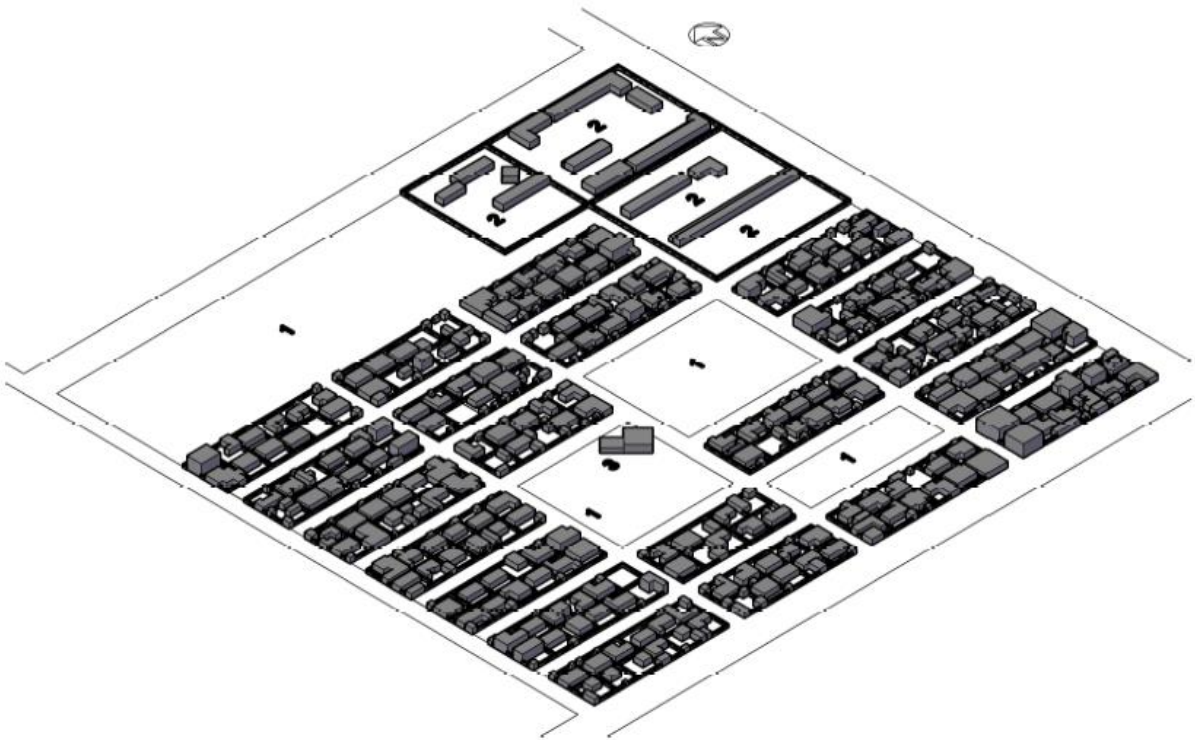

Figure 7.47 3D for third model (all houses with 4 floors, 13m). [Author]

7.8.2 3D modeling for simulation

The model is prepared by using Auto CAD as shown in figure (7.47), then it is converted to Ansys 16 CFD to study wind pattern around buildings.

7.8.3. Computational Domain and Mesh

The model is defined by a calculation domain with a size of 694m, 613m and 65 meters in directions x, y and z, respectively, according to the best practice guide line described in chapter four. Figure (7.48).

The continuity and NAVIR- STOCK equations were used to determine the wind pattern around buildings. Tetrahedral mesh was used. The total cells reached 5,000,000 items. See figure 7.49

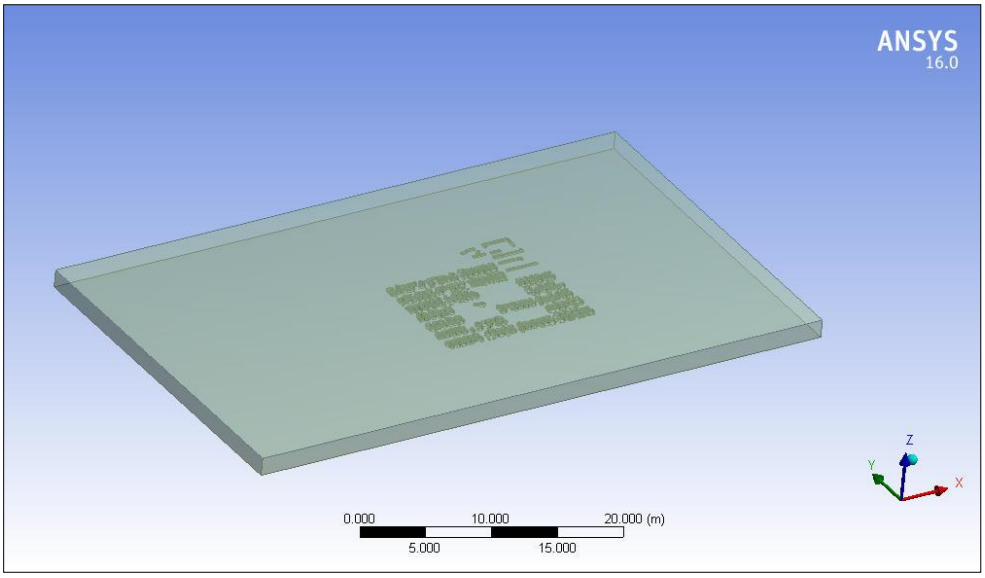

Figure 7.48 Computational domain. [Author]

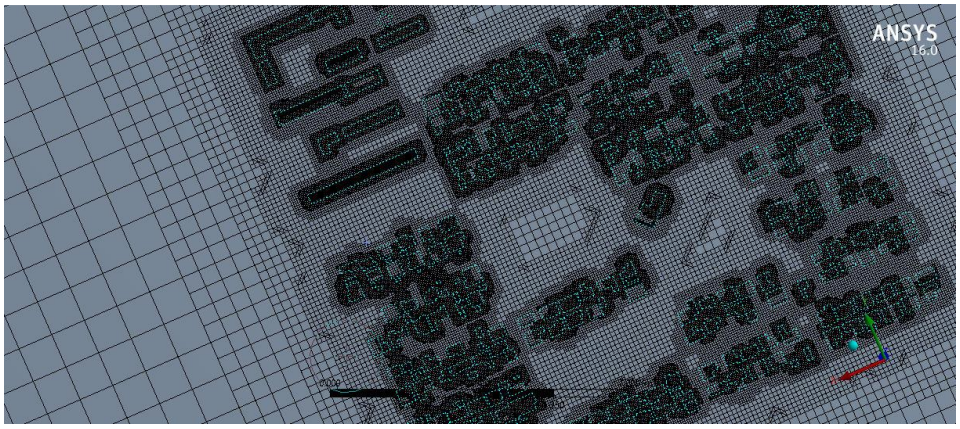

Figure 7.49 the mesh [Author]

7.8.4. Simulation and Analysis

In this model, the wind pattern is analyzed and studied within the residential area, to investigate the behavior, speed and direction of the wind, the effect of buildings, boundary walls which separate the houses and inner courtyards on the speed and direction of the wind.

Ansys CFD 16 is used for analysis of the wind speed of 6m/s, and north east as predominant direction. Navir-Stock equations were used in the analysis process. Readings is performed at different height starting at 1.5 m up to 10.5 m, the highest points in the study area.

7.8.5. Results Analysis

Wind pattern around buildings was analyzed as follows:

7.8.5.1 Wind pattern at a height 1.5m

This height is equal to the level of windows at ground floor. At this height as shown in figures 7.50, 7.51, and 7.52 the following results are obtained:

1- Wind speed decreases from 6m/s to 1.7m/s and 2.1m/s at the beginning of the residential area.
2- Wind speed around the buildings generally ranges between 2.5m/s and 0.5m/s as indicated in figures 7.50, 7.51.
3- Wind speed in the eastern and western sides of the residential area varies between 3.5m/s and 4.5m/s. It also varies between 1.5m/s and 0.5m/s inside the residential area ranges. See figure7.50.
4- In the open spaces, wind speed reaches 2.4m/s and 1.5m/s and higher than the speed inside the built-up area.
5- Wind direction changes in east- ward and west- ward streets because it is affected by the buildings next.
6- Wind speed at the beginning of row houses with open space ranges between 2m/s and 1.5m/s.

7- It is clear that the wind direction in open spaces is unstable because the buildings are located behind and in the front the open space and side streets.

8- The speed of the wind moving toward the north and south ranges between 4m/s and 3m/s. It is clear that the speed is higher than the speed in the built- up area.

9- The wind speed ranges between 2.2m/s and 2.8m/s in the side corridors of the buildings.

10- Vortexes appear behind the buildings and in the meantime the wind scatters in all directions with speed ranging between 1m/s and zero.

11- Speed in the open spaces ranges between 2.4m/s and 1.5m/s and 0.5m/s and 1m/s in the inner courtyard.

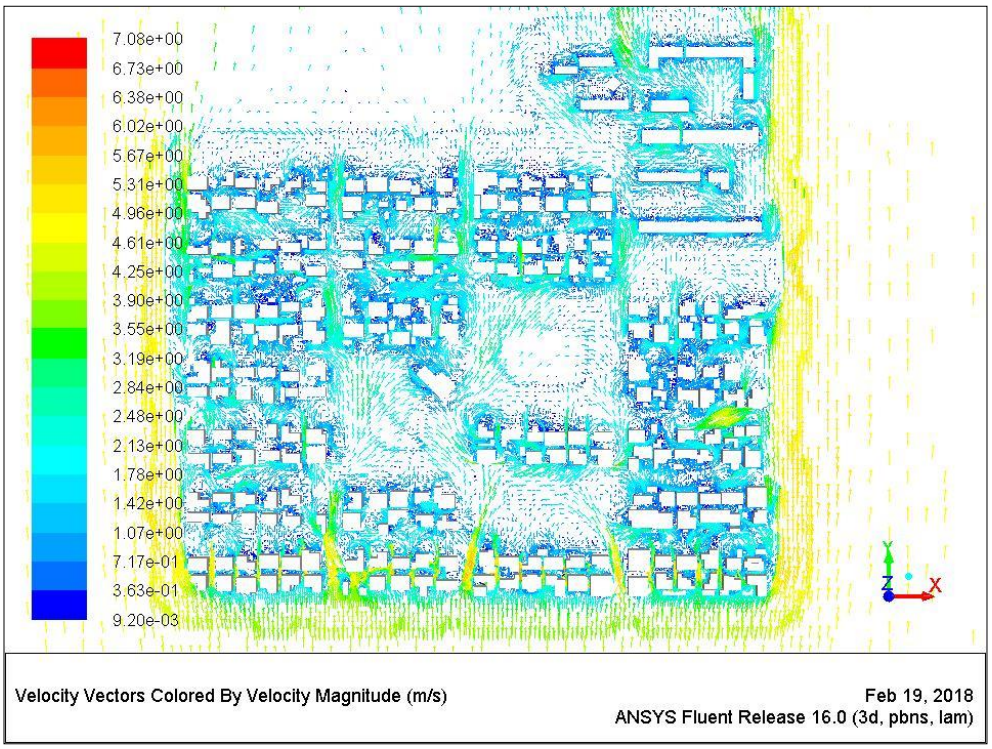

Figure 7.50 Wind pattern around buildings at a height of 1.5m [Author]

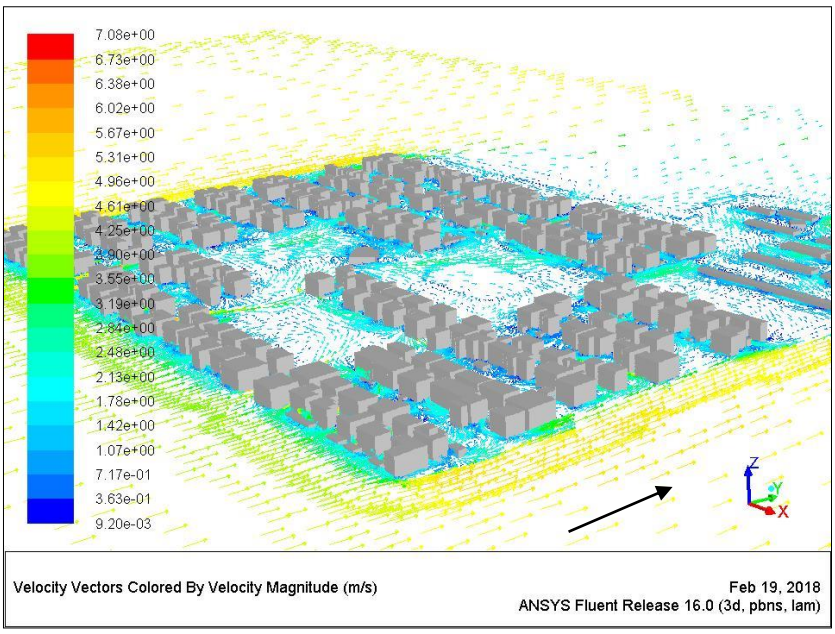

Figure 7.51 Wind pattern around buildings at a height of 1.5m [Author]

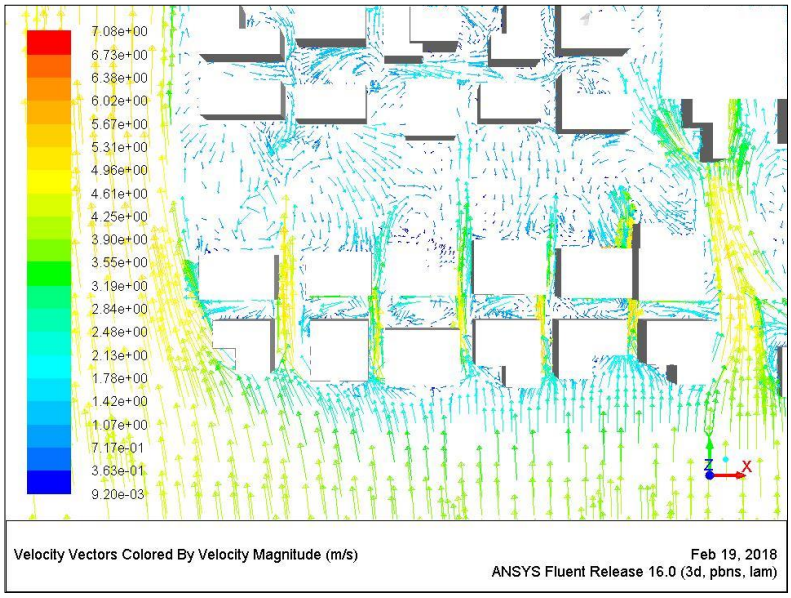

Figure 7.52 Wind pattern around buildings at a height of 1.5m [Author]

7.8.5.2 Wind Pattern at 4.5m Height

This height equals the level of windows of one-story building. At this height and from the figures 7.53, 7.54 and 7.55, the following can be deduced:

1- Wind speed in the eastern and western sides of the residential area varies between 5m/s and 4m/s. It is clear that the speed is higher than inside

residential area where it varies between 1.5m/s and 1m/s, except for the first and second rows of houses located at the beginning of the residential area.

2- Wind speed in the first and second rows of houses located at the beginning of residential area ranges between 2.4m/s and 1.7m/s.
3- Wind speed decreases between 1.5m/s and 1m/s in houses next the first and second rows.
4- Wind speed at the beginning of north- ward streets varies between 4m/s and 5m/s, and then it drops to 3.5m/s and 2.5m/s at the end of the residential area.
5- Wind speed in the open spaces is estimated at 2.5m/s and 1.5m/s, i.e. it is higher than the speed in built-up area.
6- It is noticeable that the wind in the open spaces moves to the north, north-east and north-west, because it is affected by the streets around the open space.
7- Wind speed increases slightly when it passes through the open space. In this area, it becomes between 2.5m/s and 2m/s at the beginning of houses which follow the open space.
8- Vortexes appear at this height where the wind scatters in different directions with speed ranging between 1m/s and 0.5m/s behind the houses.
9- Some wind passes east of the houses area. Then it heads toward western around the houses and scatters in different directions.
10- Some wind passes west of the houses area toward eastern around the houses and then scatters in various directions.

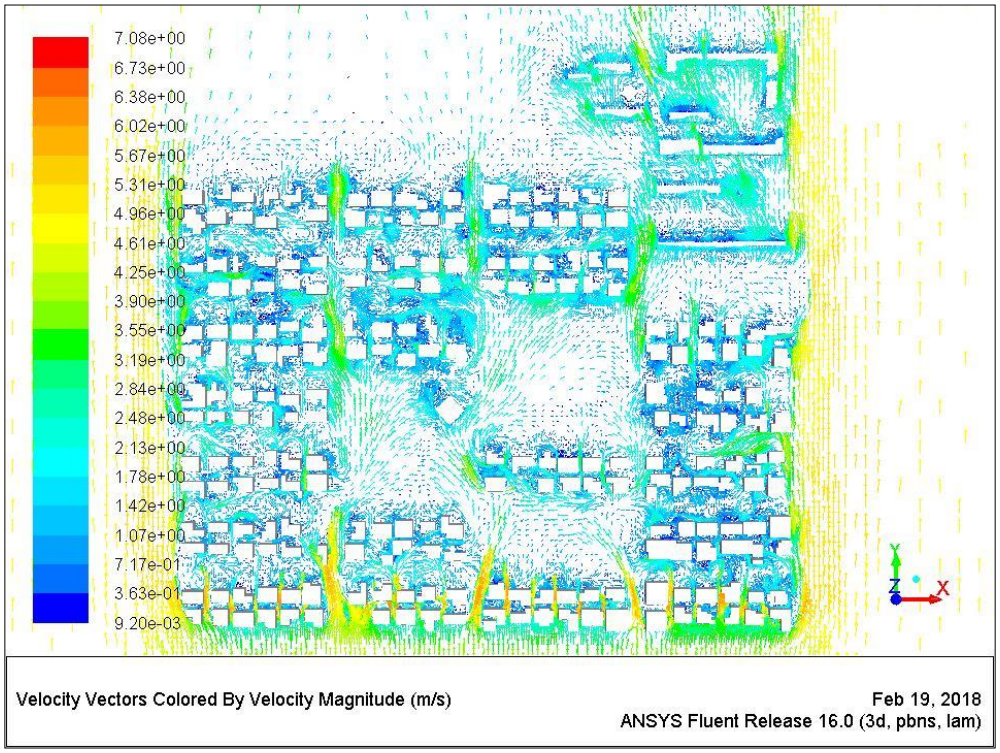

Figure 7.53 Wind pattern around buildings at a height of 4.5m [Author]

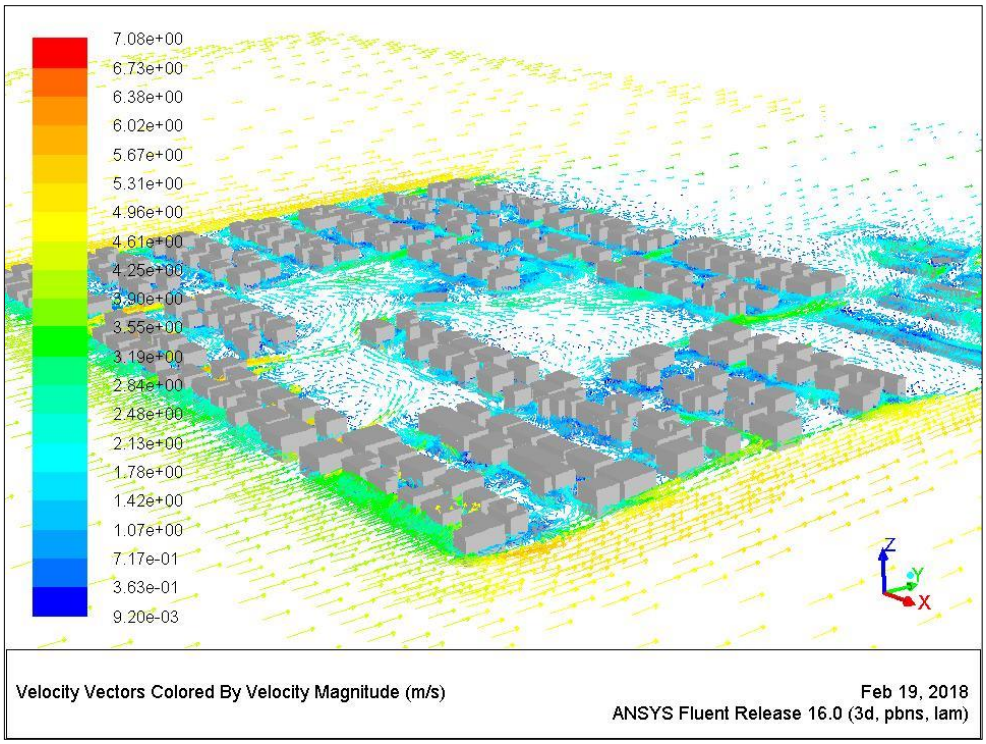

Figure 7.54 Wind pattern around buildings at a height of 4.5m [Author]

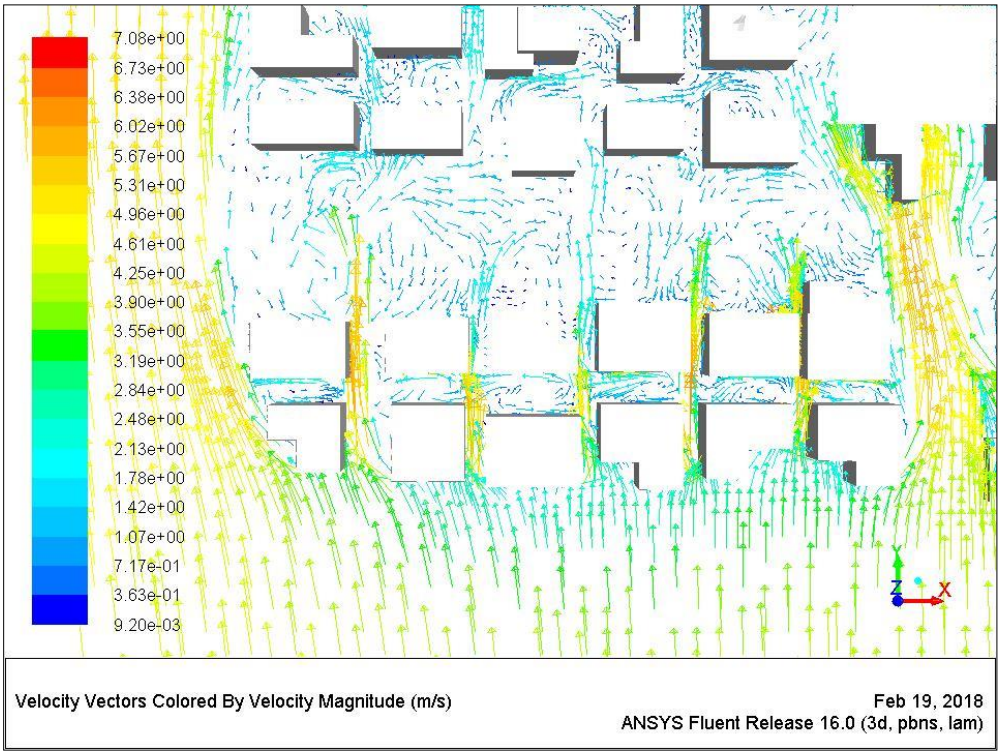

Figure 7.55 Wind pattern around buildings at a height of 4.5m [Author]

7.8.5.3 Wind Pattern at 7.5m Height

At this height and according to the figures 7.56, 7.57 , 7.58, the following can be concluded:

1- Wind speed in western and eastern side of the residential area ranges between 5m/s and 5.3m/s. i.e. it is higher than speed at height of 1.5m and 4.5m of the same place.

2- Wind speed in the side corridors of the first and second rows located at the beginning of the residential area varies between 4m/s and 5m/s. The speed then drops between 2.4m/s and 1.4m/s in the next rows.

3- Wind speed in open spaces ranges between 2.8m/s and 1.8m/s.

4- Wind direction becomes irregulars in open spaces, because it is affected by the buildings and streets.

5- Vortexes appear at the same place as happened at height of 1.5m and 4.5m.

6- Wind speed increases slightly when it passes through open spaces. It ranges between 3.1m/s and 2.1m/s at the first rows of houses located next to the open space.

7- Wind speed decreases between 0.5m/s and 1.5m/s in the inner courtyards of houses situated behind the houses overlooking the open spaces

8- The direction of wind in internal courtyards located between the building and the boundary wall is irregular. At this point, the speed ranges between 1.0m/s and 0m/s.

9- The speed of street wind blowing toward east and west ranges between 2m/s and 1.7m/s These streets separate the houses rows.

10- The wind direction in east and west streets is irregular.

11- The speed of wind coming from the north- ward and south- ward streets in to inner courtyards ranges between 2.4m/s and 1.4m/s.

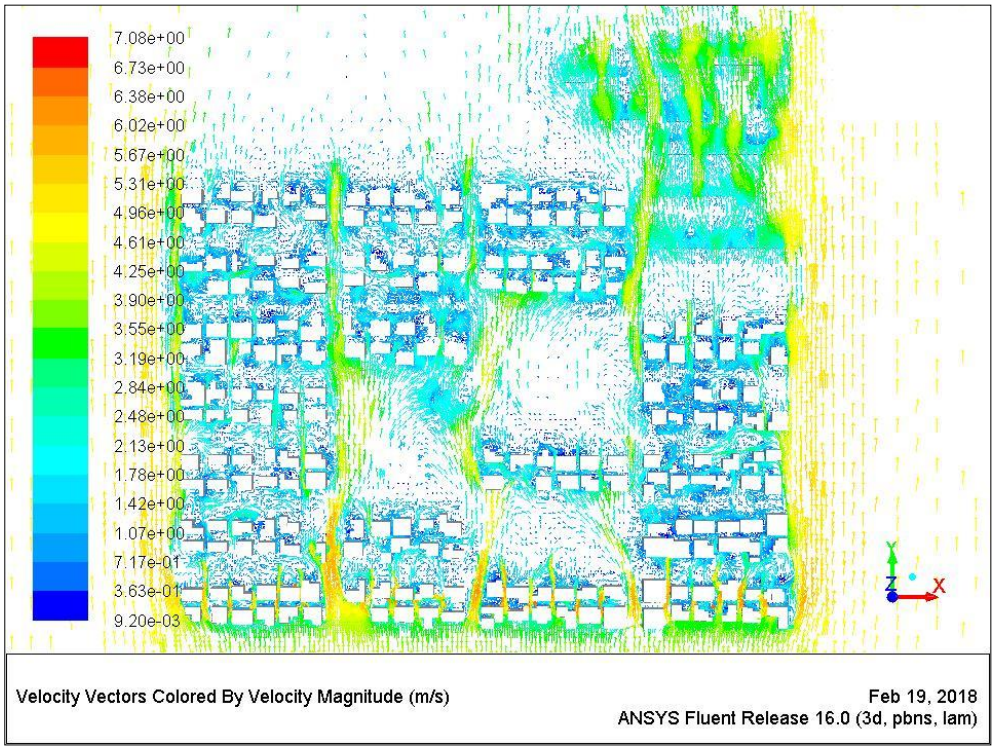

Figure 7.56 Wind pattern around buildings at a height of 7.5m [Author]

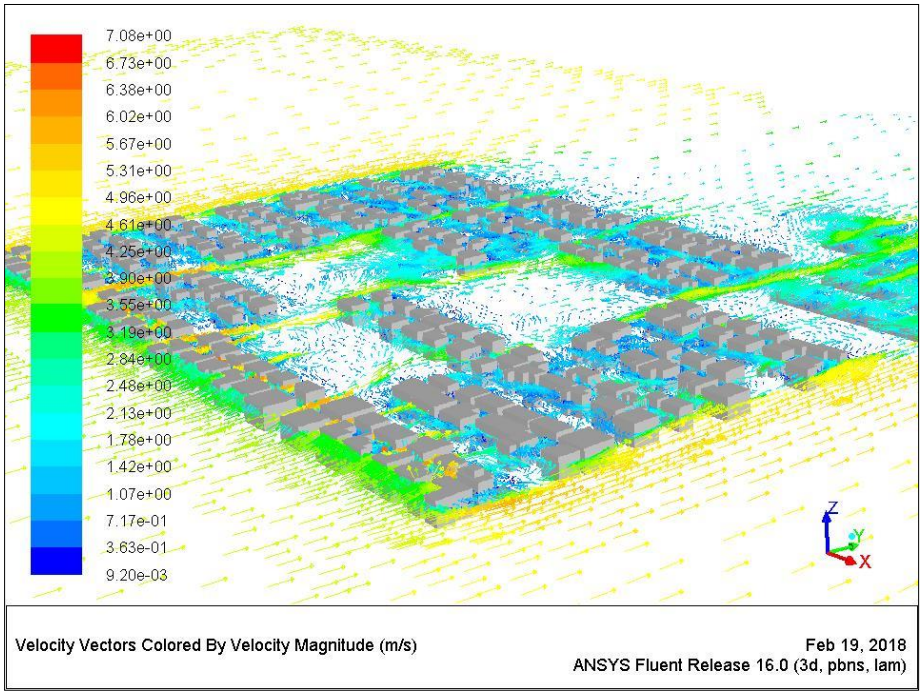

Figure 7.57 Wind pattern around buildings at a height of 7.5m [Author]

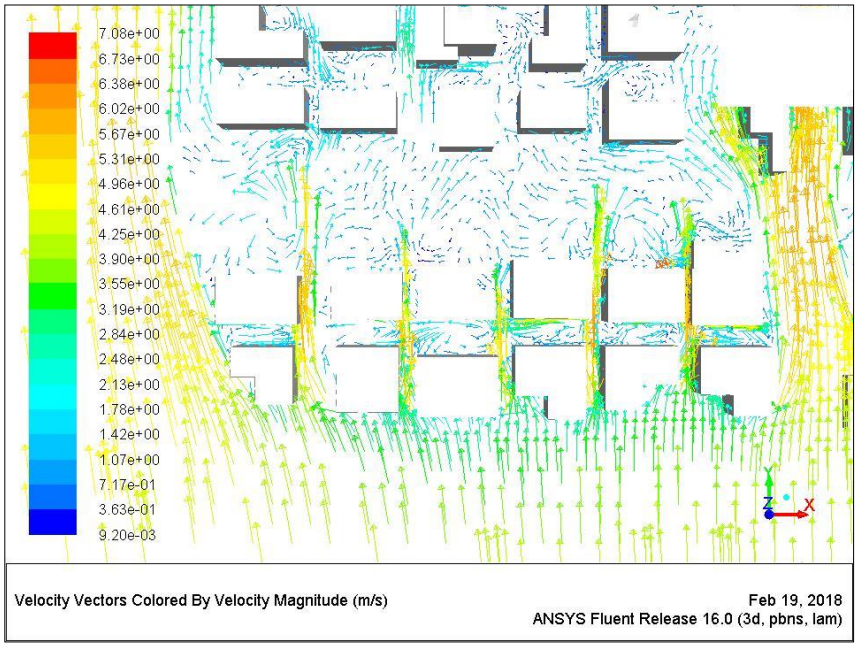

Figure 7.58 Wind pattern around buildings at a height of 7.5m [Author]

7.8.5.4 Wind Pattern at 10.5m Height

At this height according to the figures 7.59, 7.60 and 7.61, the following points have been noted:

1- Wind speed in inner corridors of the first and second rows of the houses situated at the beginning of the residential area, range between 5.1m/s and 4.6m/s.
2- Wind speed in in the center of open space reaches 1.7m/s and 4.6m/s in the sides of the same area.
3- Wind direction is irregular inside the open spaces.
4- Vortexes appear behind the building at the same place as happened at building with less height.
5- The direction of wind blowing toward east and west streets is irregular. It ranges between 1m/s and 2m/s.

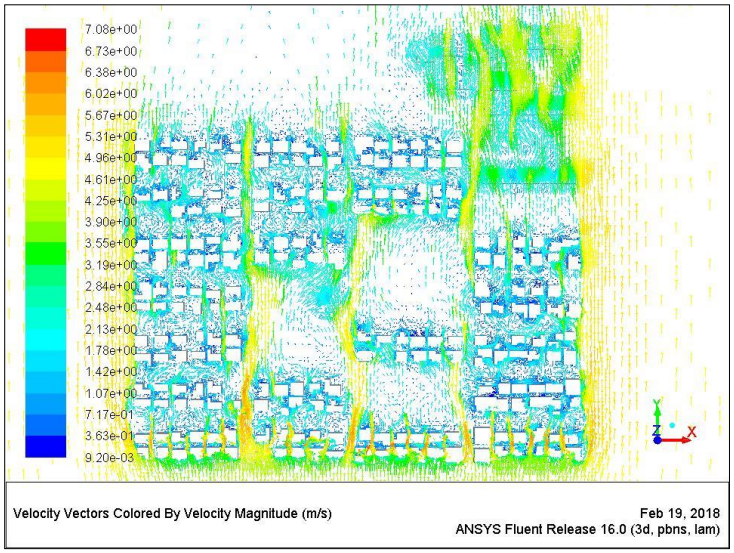

Figure 7.59Wind pattern around buildings at a height of 10.5m [Author]

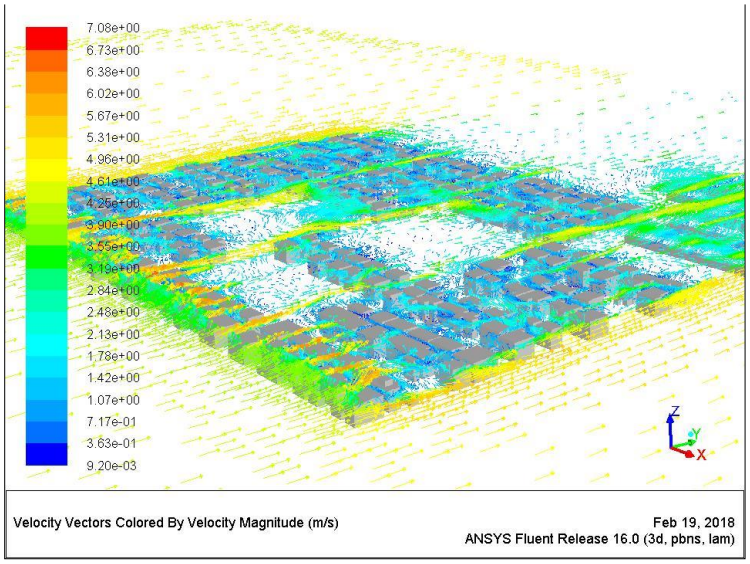

Figure 7.60Wind pattern around buildings at a height of 10.5m [Author]

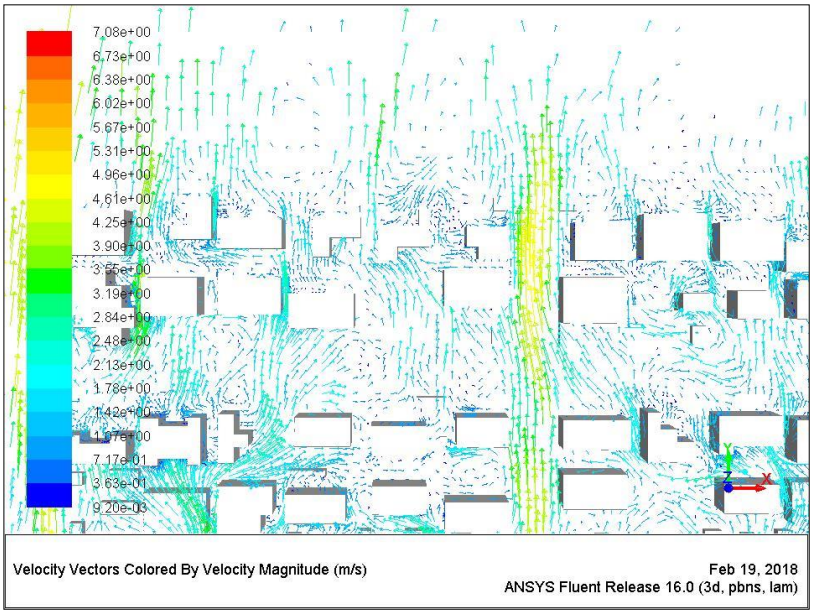

Figure 7.61Wind pattern around buildings at a height of 10.5m [Author]

7.9. Wind Pattern Analysis for Fourth Model

7.9.1. Model Description

Although this model is identical to the third one in terms of the area, components of the residential area and number of houses, the fourth model consists of two parts: The southern part consists of four-storey building (13m), and the northern part which draws one-storey building (4m). The wind blows from the south between June and September.

7.9.2. Simulation Modeling

The model is prepared with Auto CAD, as in figure (7.62), then it is converted to Ansys 16 CFD to study wind pattern around buildings.

7.9.3. Computational domain and grid

This model is defined by a calculation domain with size of 694m, 613m and 65 meters in directions x, y, and z, respectively as happened in the third model. According to the best practice guide line discussed in chapter four, figure (7.63), the tallest building in the two models is four-storey (13m). The continuity and NAVIR- STOCK equations were used to determine the wind pattern around buildings in addition to tetrahedral mesh. The cells total 5,000,000 items. See figure 7.63

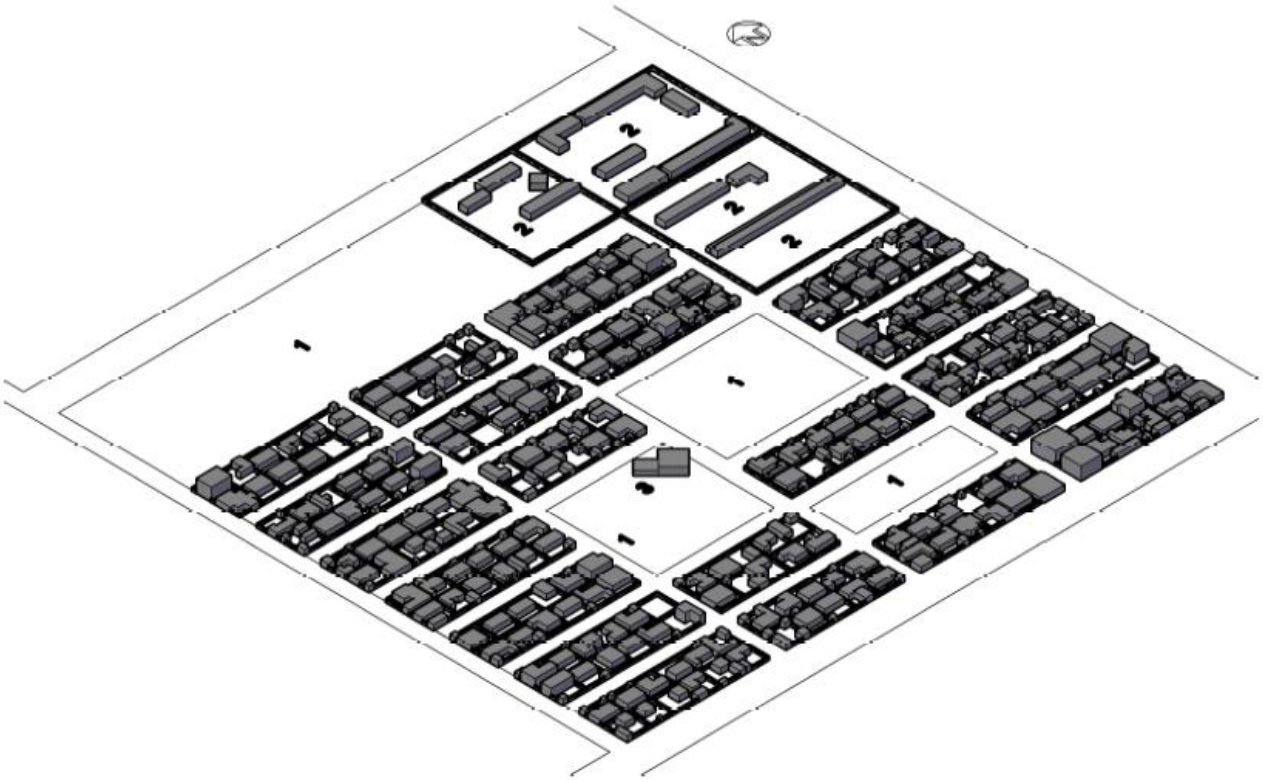

Figure 7.62 Fourth model [Author]

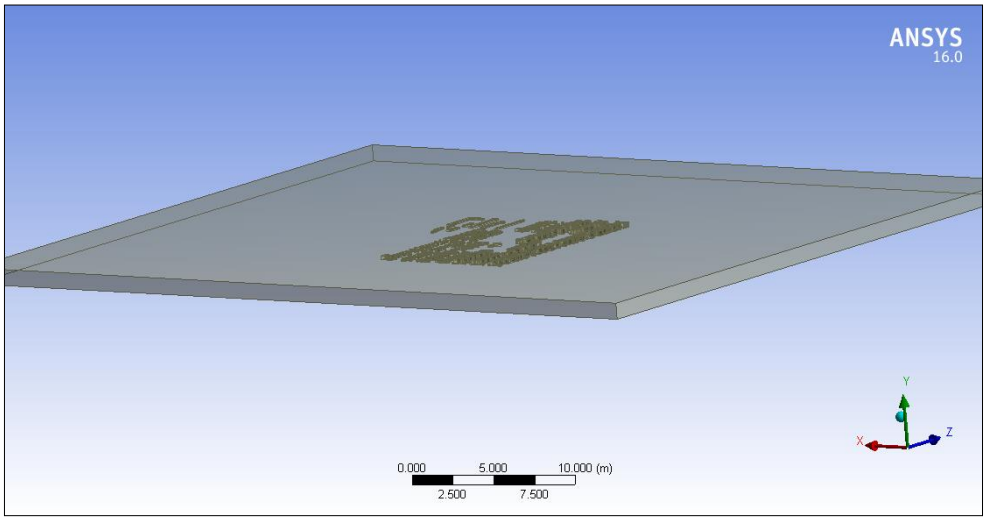

Figure 7.63 Computational domain [Author]

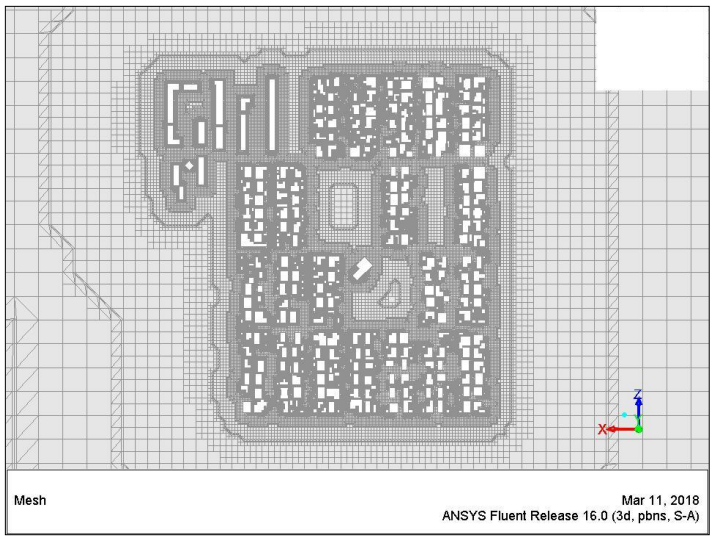

Figure 7.64 Computational mesh [Author]

7.9.4. Simulation and Analysis

In this model, wind pattern is analyzed between June and September. In this period, the wind blows from the south to the north. The wind passes through high buildings and then to low ones.

Wind pattern is analyzed and studied in the residential area under study to investigate its behavior, speed, and direction. Wind is also analyzed to examine the effect of buildings and boundary walls which separate the houses and the inner courtyards on the wind speed and direction.

Ansys CFD 16 is used for the analysis of the wind speed at 4.5m/s. The north east wind is predominant in the study area. Navir-Stock equations were used in the analysis process. Readings is made at different height levels ranging between 1.5m up to 10.5 m, the highest point in the study area.

7.9.5. Results Analysis

7.9.5.1 Wind pattern at a height 1.5m

At this height and according to the figures 7.65, 7.66 the following results were concluded:

1- Wind speed outside the residential area (east and west sides) varies between 3.7m/s and 4.4 m/s. The wind speed outside is higher than the speed inside the residential area where the speed ranges between 2.9 m/s and zero.

2- It can be noted that the wind velocity around the high buildings (four-storey) ranges between 3.5 m/s and 1.5 m/s, while it ranges between 0.75 m/s and zero around the low buildings (one-storey) situated behind the high buildings.
3- Wind speed ranges between 2.9 m/s and 4 m/s around buildings in the first row from the southern side. The speed decreases as it heads north towards the low buildings, where the speed ranges between 2.2 m/s and zero.
4- Wind speed around high buildings (four-storey) varies between 3.5 m/s and 1.5 m/s and 1.25 m/s and 0.5 m/s. in the low buildings (one-storey)
5- Wind heading to the east and west in internal streets with eastward and west- ward direction, the wind speed ranges between 2.2 m/s and 1.m/s.
6- Wind speed in the northern and southern streets varies between 3.5 m/s and 2.9 m/s. In this case, the speed is higher than the speed around the buildings.
7- The appearance of the scattered vortexes and wind in different directions in the inner courtyards of the dwellings is visible.

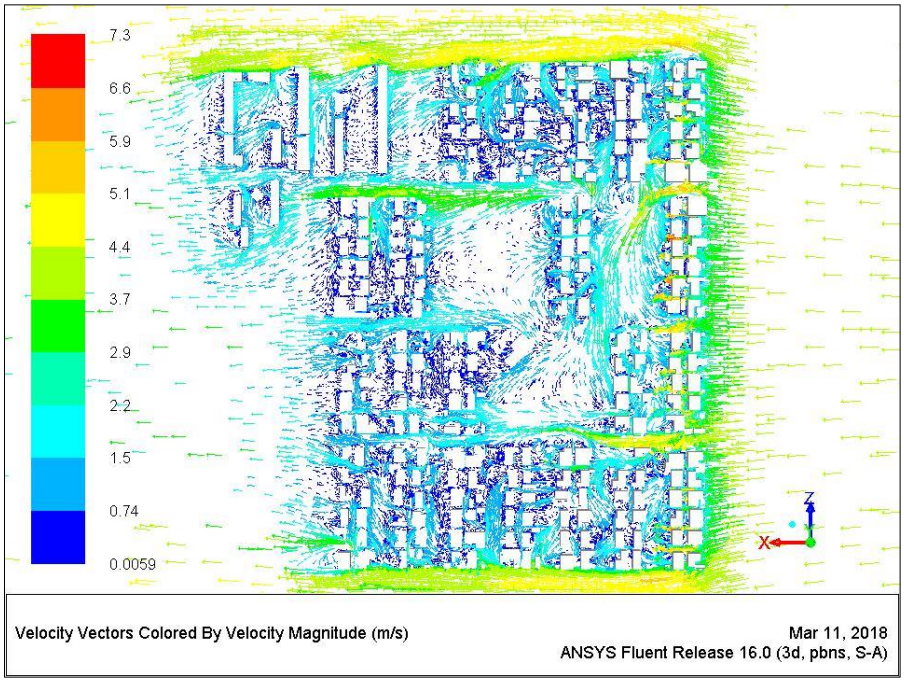

Figure 7.65Wind pattern around buildings at a height of 1.5m [Author]

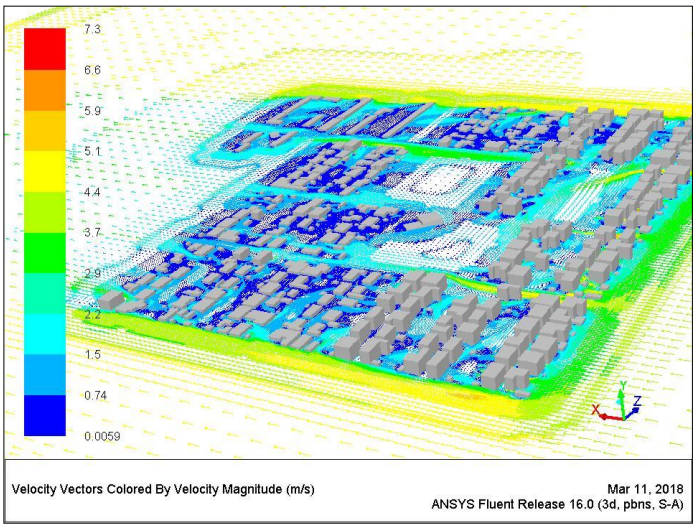

Figure 7.66 Wind pattern around buildings at a height of 1.5m [Author]

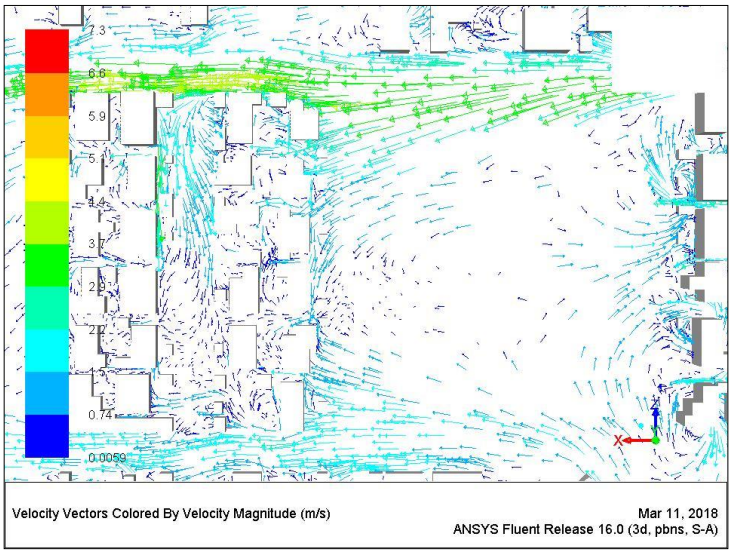

Figure 7.67 Wind pattern around buildings at a height of 1.5m [Author]

7.9.5.2 Wind Pattern at 4.5m Height

At this height and from the figures 7.68 and 7.69, it can be concluded that:

1- Wind speed around high-rise buildings (four-storey) varies between 3.9 m/s and 1.9 m/s. At this level, is speed is higher than the speed around the low buildings where wind speed diverges between 1.5 m/s and zero.

2- An area such as a red frame emerges behind high buildings (four-storey). The wind speed in this area fluctuates between 0.8 m/s and zero.

3- A triangular shaped area appears behind tall buildings because of the street on the eastern and western sides.

4- It is clear that the wind is slightly skewed from north to east and west, when it crosses through high buildings. The wind speed ranges from 0.75 m/s to 1.5 m/s forming a triangle shaped area.
5- High buildings block the wind from low buildings behind them up to 110 m away.
6- Wind speed in the outskirts of the residential area (east and west) ranges range between 2.4 m/s and 4 m/s.
7- Different vortexes and wind appear in the low built area.

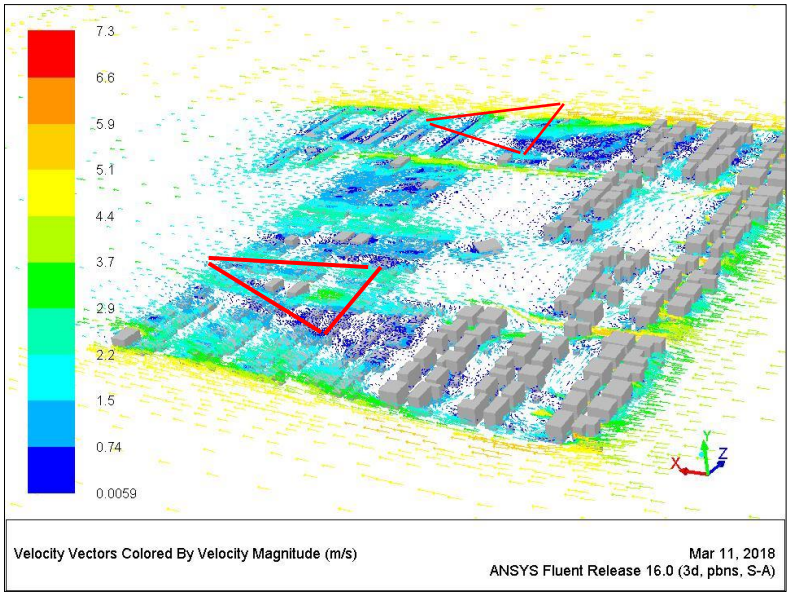

Figure 7.68Wind pattern around buildings at a height of 4.5m [Author]

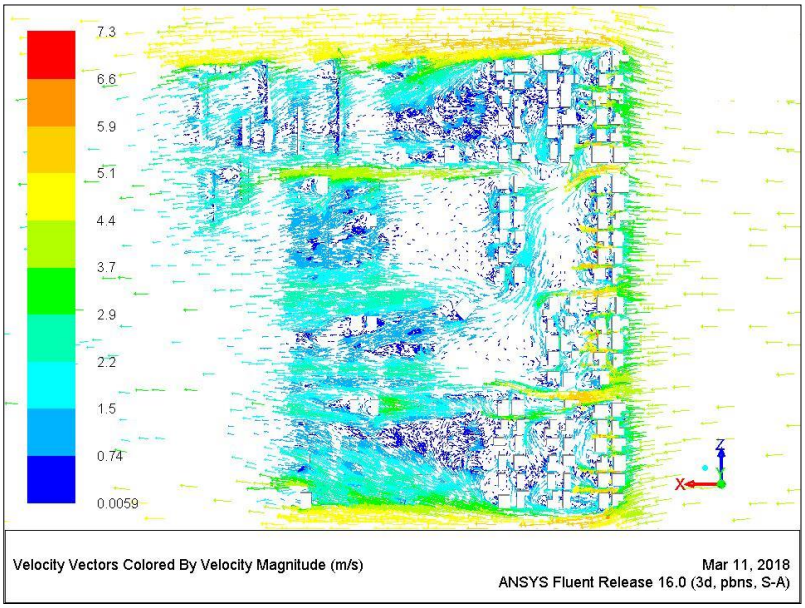

Figure 7.69 Wind pattern around buildings at a height of 4.5m [Author]

7.9.5.3 Wind Pattern at 7.5m Height

At this height and according to the figures 7.70, 7.71 the following points are noted:

1- Wind speed around the high buildings (four-storey) varies between 2.5 m/s and 3 m/s in the first row. It decreases as it is goes north-ward with speed reaching between 0.5 m/s to zero at the third row.

2- Wind speed in the north and south streets ranges between 4.5 m/s and 3.5 m/s, then it decreases as it blows north-ward, behind the high buildings.

3- At this height a triangular shaped area appears behind the high buildings.

4- Wind speed around the buildings, in the third row ranges from 0.7 m/s to 1.7 m/s as a result of a 70m wide open space separating the second and third row of the high buildings. (the area in the red frame figure 7.70).

5- The wind speed in the side corridors varies between 3 m/s and 2.25 m/s at the first row of the high buildings, while the speed drops to 1.5 m/s and 1 m/s at the third row.

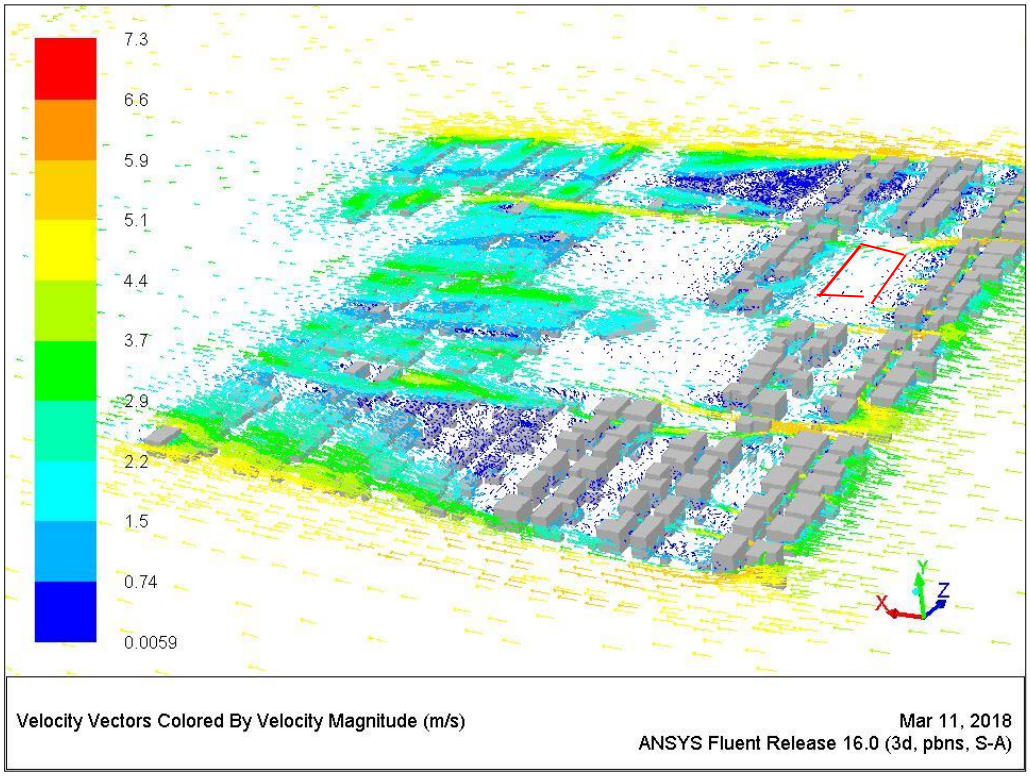

Figure 7.70 Wind pattern around buildings at a height of 7.5m [Author]

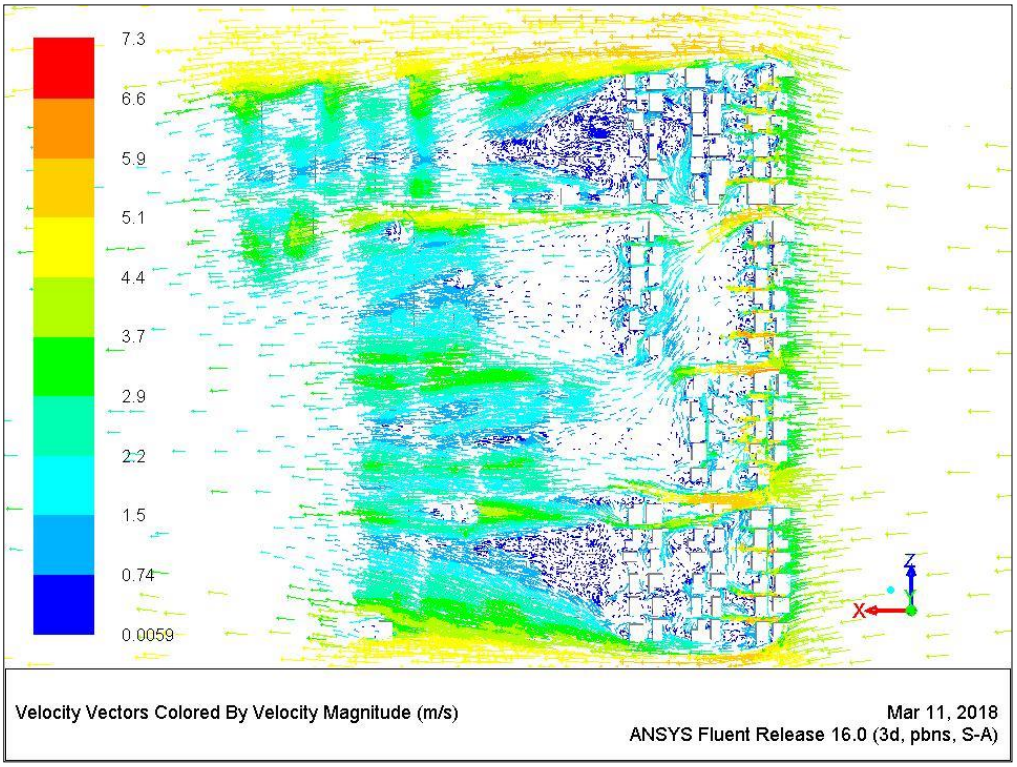

Figure 7.71 Wind pattern around buildings at a height of 7.5m [Author]

7.9.5.4 Wind Pattern at 10.5m Height

According to the figures 7.72, 7.73, the following results are concluded at this height:

1- The wind speed here is higher than the speed at previous heights; it ranges from 7 m/s to 5.3 m/s at the beginning of the residential area.

2- The speed of wind around the first row of buildings varies between 7 m/s and 5.3 m/s, and decreases between 1.5 m/s and 0.5 m/s in the third row.

3- Wind speed around third row of buildings located behind the open space ranges between 1.2 m/s and 2.2 m/s. That means it is higher than the speed around the row of buildings located behind other buildings.

4- Wind speed inside the corridors of the first row is estimated between 4 m/s and 5.5 m/s. It decreases as it blows north-ward varying between 2.2 m/s and 1.5 m/s.

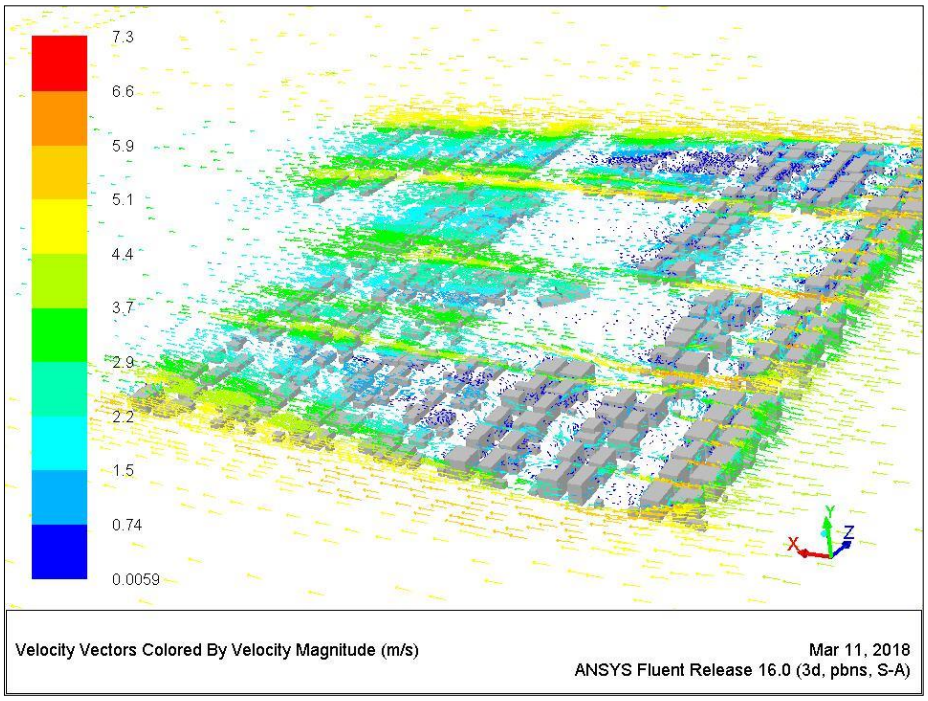

Figure 7.72 Wind pattern around buildings at a height of 10.5m [Author]

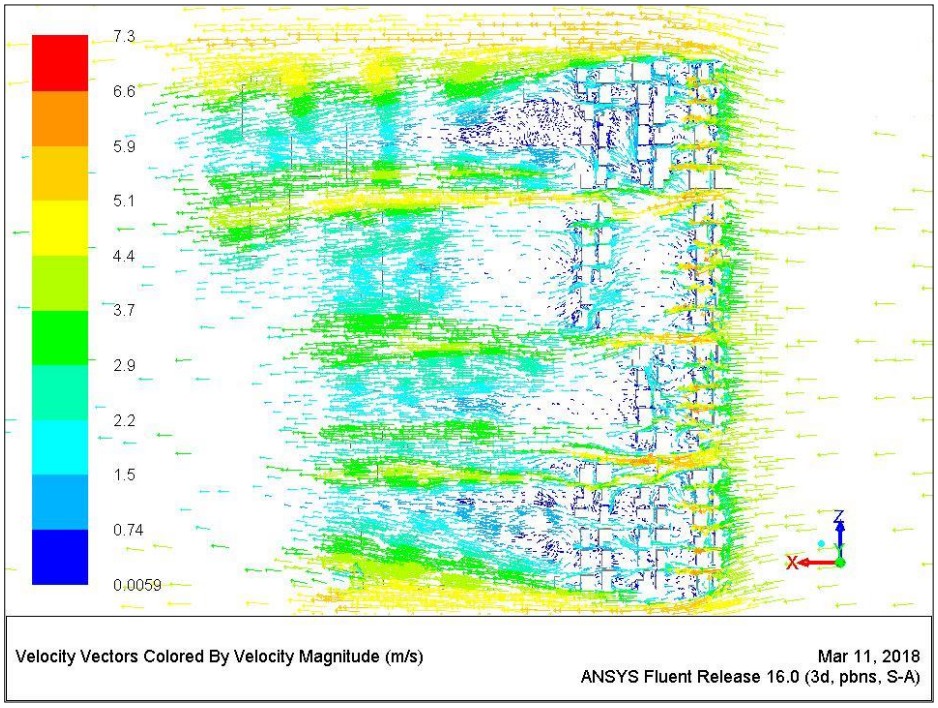

Figure 7.73 Wind pattern around buildings at a height of 10.5m [Author]

7.10. Wind Pattern Analysis of Model Five

7.10.1. The model description

This model is identical to the fourth one in terms of the area, components of the residential area and number of houses. According to the model, the residential area under study consists of two parts: The southern part includes four-storey buildings (13m), while the north part draws one-storey buildings (4m). The wind blows from the north between October and May.

7.10.2. Modeling for Simulation

The model is prepared with Auto CAD, as done in figure (7.62), then it is converted to Ansys 16 C FD, to study wind pattern around buildings.

7.10.3. Computational Domain and Grid

Like the fourth model, this model is defined by a calculation domain with size of 694m, 613m and 65 meters in directions x,y and z, respectively, according to the best practice guide line mentioned in chapter 4. Figure (7.63).

The continuity and Navir-Stock equations along with Tetrahedron mesh were used to determine the wind pattern around buildings. The total cells reach 5,000,000 items. See figure 7.64

7.10.4. Simulation and Analysis

In this model, the wind pattern is analyzed and studied in the residential area to examine its behavior, speed and direction, It also tends to explore the effect of buildings, boundary walls which separate the houses and inner courtyards on the speed and direction of the wind.

Ansys CFD 16 is used for the analysis of the wind speed at 4.5m/s. The north east wind is predominant in the study area . Navir-Stock equations were used in the analysis process. Readings is made at different height levels ranging between 1.5m up to 10.5 m, the highest point in the study area.

7.10.5. Results Analysis

7.10.5.1 Wind Pattern at 1.5m Height

At this height according to figures 7.74 and 4.75, the following results have been reached:

1- The wind speed at the beginning of the residential area, and its sides ranges between 3.5 m/s and 4.5m/s.
2- The speed of wind around the buildings of the first row of the low buildings (one storey) varies between 3.5m/s and 4.5m/s, and the speed decreases as we head south.
3- The wind speed around the buildings of the second row of low buildings varies between 1.8m/s and 2.5m/s, and the speed around third row ranges between 0.9m/s and 1.8m/s.
4- It is clear that, the wind speed ranges from 2.2m/s to 3m/s in the open space located beyond the rows of buildings.
5- The speed of wind in the north and south streets ranges between 2.7m/s and 3.5m/s. It is also faster than around the buildings.
6- The wind changes its direction when it collides with high-rise buildings (four-storey) changing to east and west. As a result vortexes emerge in this area.
7- The wind speed varying from 2.7m/s to 3m/s increases around the high buildings (four-storey) located behind the open space.

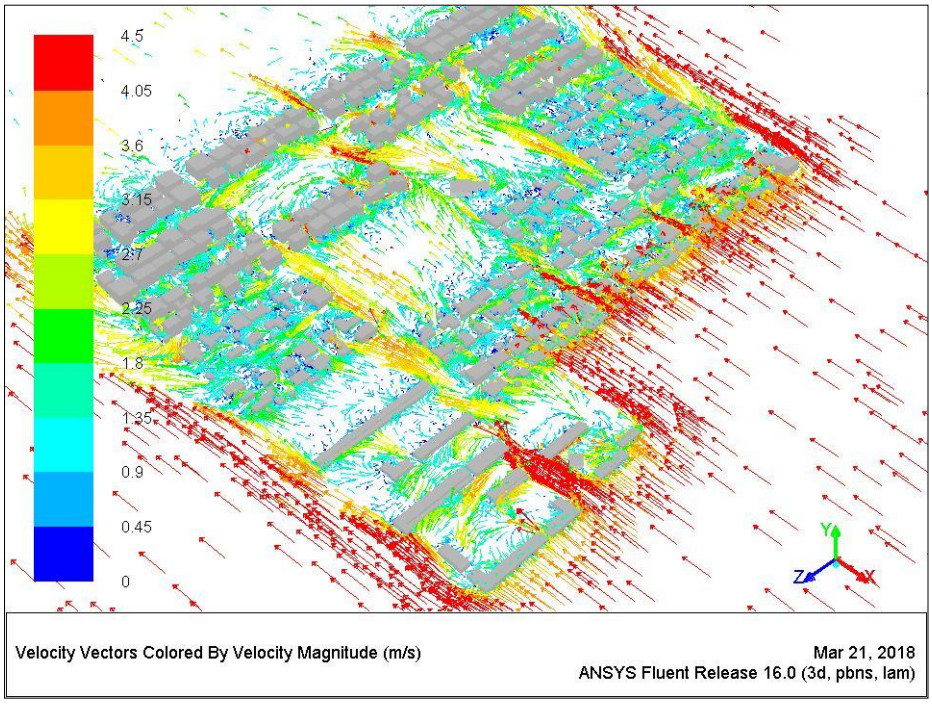

Figure 7.74 Wind pattern around buildings at a height of 1.5m [Author]

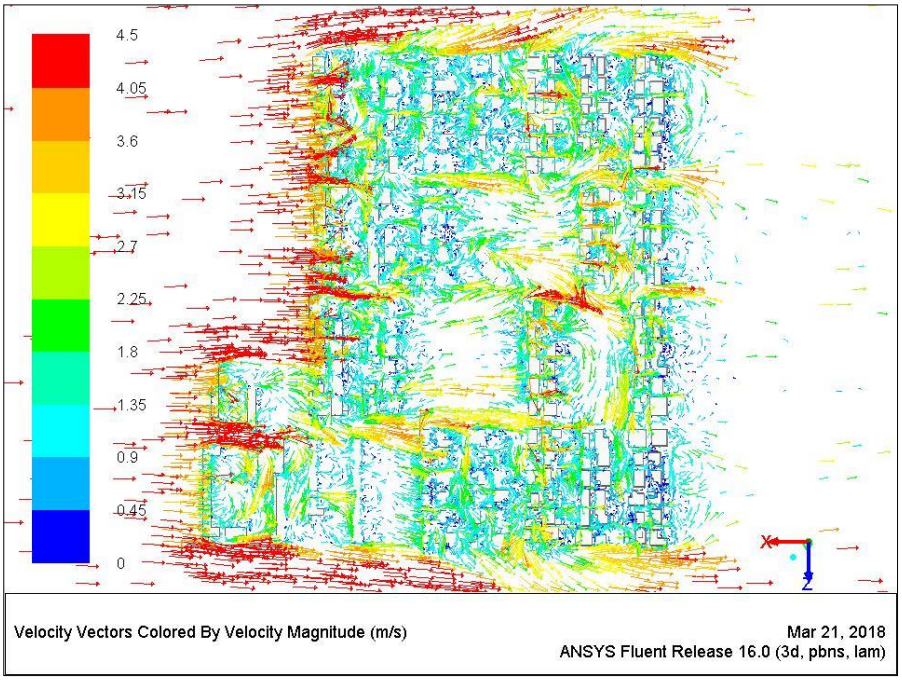

Figure 7.75 Wind pattern around buildings at a height of 1.5m [Author]

7.10.5.2 Wind Pattern at 4.5m Height

At this height according to the figures 7.76 and 4.77, it can be concluded that:

1- The wind goes through the top of the first row of low buildings (one-storey) at speed ranging between 3m/s and 4m/s.

2- The speed drops to 1.35m/s and 2.7m/s in the rows of low buildings next the first row.

3- The wind speed in the open space located behind the low buildings varies between 1.8m/s and 3.8m/s.

4- The speed of wind around high buildings located behind low buildings ranges between 1.3m/s and 2.7m/s.

5- The wind screws to the south-east and south-west directions when it collides with high buildings.

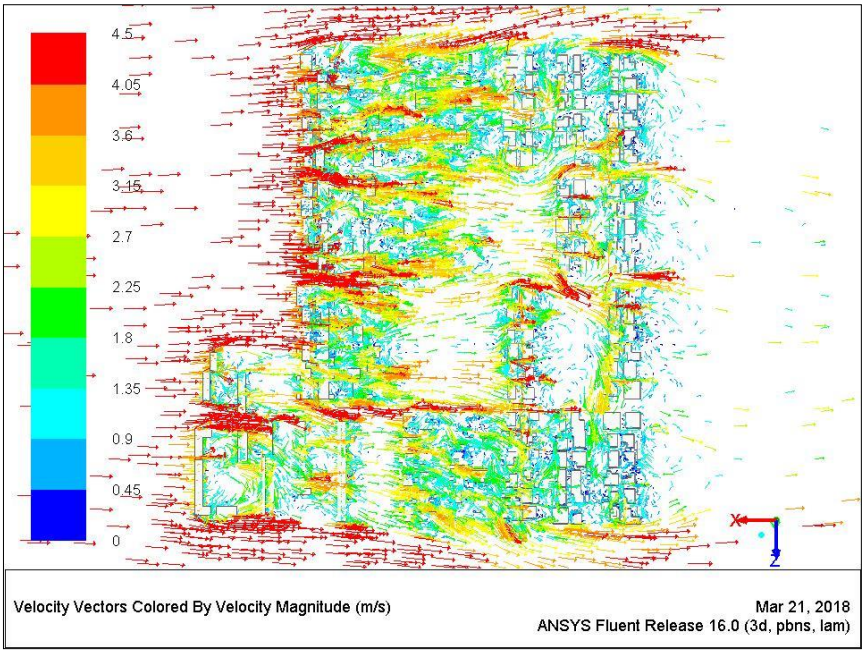

Figure 7.76 Wind pattern around buildings at a height of 4.5m [Author]

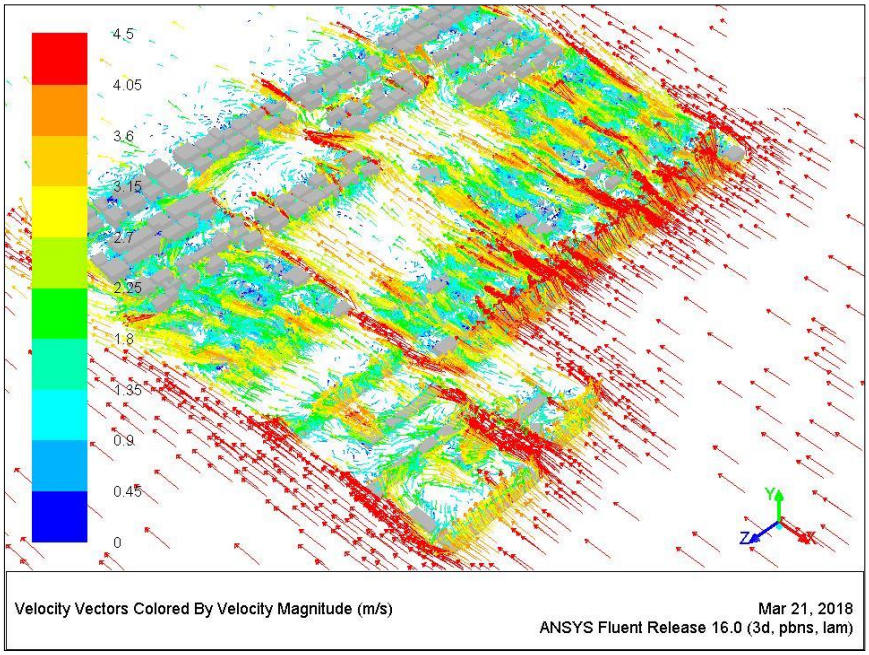

Figure 7.77 Wind pattern around buildings at a height of 4.5m [Author]

7.10.5.3 Wind Pattern at 7.5m Height

Based on figures 7.78 and 4.79, the following results have been reached:

1- The wind passes over low buildings at speed ranging from 2.2m/s to 4m/s.

2- It's obvious that the wind direction in the open spaces located after the low buildings is fixed to the south. Moreover, there are no vortexes or scattered wind as happened at 1.5m.
3- The direction of the wind changes to the top, east and west, when it collides with high buildings.
4- The wind speed around high buildings varies between 2.7m/s and 3.5m/s.
5- Vortexes exist behind the high buildings where the wind speed in this area ranges from 1.9m/s to 1.3m/s.
6- Wind disperses in different directions in the open space in the middle of high buildings.
7- The wind speed behind the last row of high buildings ranges between 0.45m/s and 1m/s with no vortexes in this area.

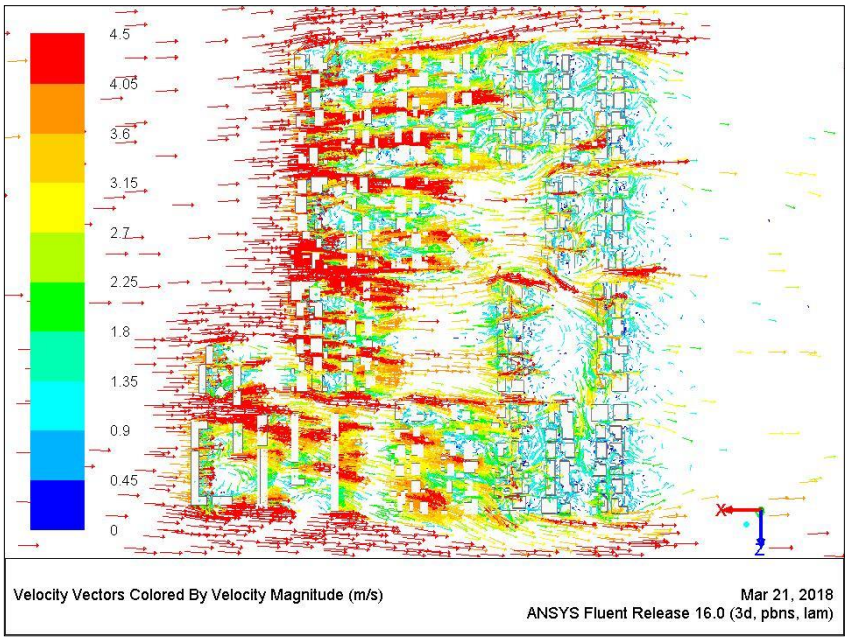

Figure 7.78 Wind pattern around buildings at a height of 7.5m [Author]

7.10.5.4 Wind Pattern 10.5m Height

At this height, and according to figures 7.80 and 4.81, the researchers arrived at the following:

1- Low buildings do not affect the wind pattern (speed or direction).
2- The wind speed around the first row of high buildings differs between 2.7m/s and 3.5m/s.

3- It is noted that the wind disperses in the open space in the middle of the high buildings. The speed is between 0.9m/s and 2m/s.

4- It is noted that the second row of high buildings located next the open space ranges between 2m/s and 2.7m/s.

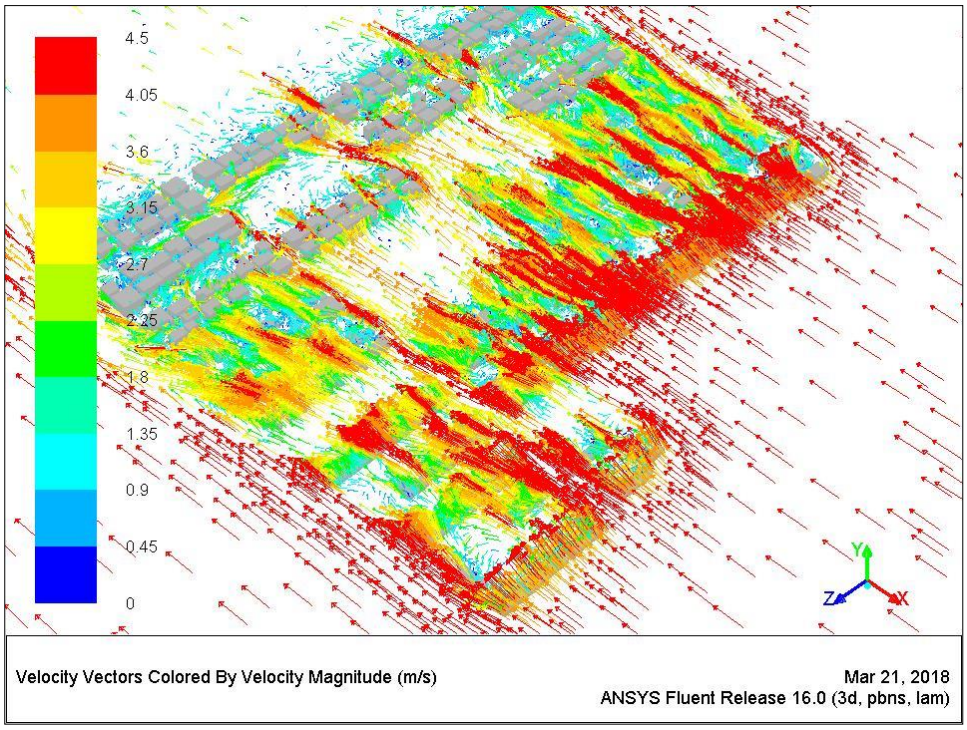

Figure 7.79 Wind pattern around buildings at a height of 7.5m [Author]

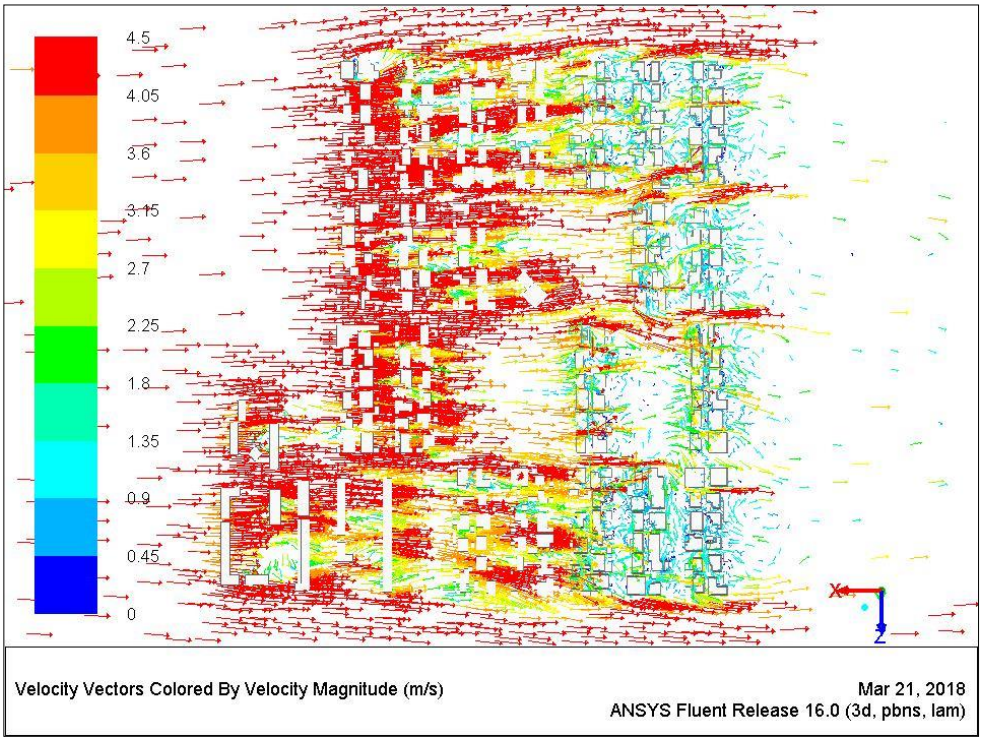

Figure 7.80 Wind pattern around buildings at a height of 10.5m [Author]

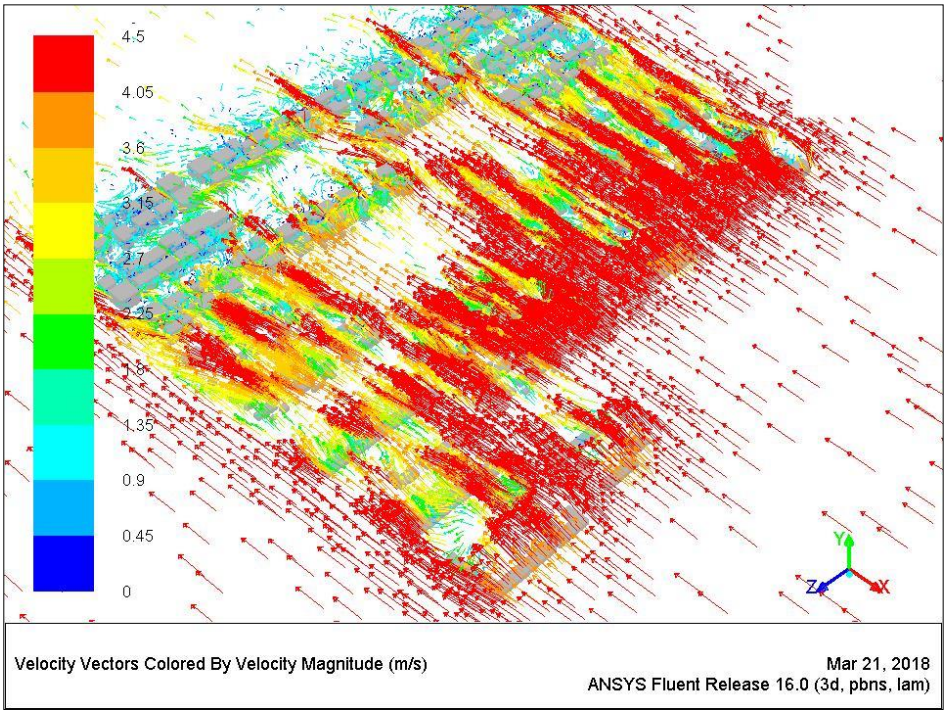

Figure 7.81 Wind pattern around buildings at a height of 10.5m [Author]

7.11. Summary of Results

Wind pattern is analyzed in two pilot models and five models with different sizes and dimensions taken from the study area. The first pilot model is designed for a small building with dimensions 4x4x4 m, and the second one is designed for the same building. . The first model consists of 12 houses. The second model represents the existing situation of the study area which consists of 242 houses, three squares (public spaces) with different dimensions, mosque and schools. The third model represents the study area where the all houses have same heights (13 m) according to the building regulations. The fourth model represents the study area where the houses are located on southern part with same heights (13m), while the houses located on northern have one storey. The wind blows from south to north. The fifth model is same as fourth one. The only difference is that the wind blows from north to south.

Ansys CFD16 was used to simulate and study wind pattern around the buildings. The analysis resulted in the detailed results mentioned bellow. The results can be summarized as follows:

7.11.1. Results obtained from the first pilot model

1- Data was successfully entered in Ansys 16 CFD.

2- The program reached solution and the data is analyzed

3- No results related to wind pattern were obtained from this model.

7.11.2. Results obtained from the second pilot model

In this model, the following results were reached:

5- The wind speed drops to 75 % when it collides with building where it scatters in all directions.

6- The wind speed decreases in the adjacent parts of the building on both sides, and increases as it moves away from the building on both sides.

7- The vortices zone appears behind the building and continues twice the height of the building.

8- The wind returns to its normal speed after 12 times of the height of the building.

9- The results are identical between the two models (mesh 0.5 and 0.1) with only difference in the form of the wind pattern. This more clear and focused in the case of the mesh 0.1.

10- The building does not affect the wind passing through on its sides with a distance of three times the width of the building.

11- For CFD simulation, the mesh dimensions should be (0.1 units) or smaller to reach accurate results.

7.11.3. Results obtained from the first model

1- Wind speed at the height of 1m and 1.5 m at the beginning of the model drops from 6 m/s to range between 2.9 m/s to 3.7 m/s around the buildings.

2- The speed reduced to 1.7 m/s in the side corridor after 20 m from the beginning of the model.

3- From this model, it can be noted that the yellow lines appeared inside the first row of houses, while blue lines appeared in the second row of

houses. This means that the speed ranged between 2.7 m/s at the first row and 1 m/s at the end of the second row.

4- In this type of arrangement, it clear that wind speed in the area between the house and boundary wall varies from one area to another. It ranges from 0.2m/s to 1.2m/s depending on the distance between the house and boundary wall, the height of the house, and the width of side corridors. See figure 7.24.
5- It is noted that high houses block the wind from the lower ones; therefore, houses with different heights should not be placed near each other in the direction of the wind.
6- The vortexes appear in the same place where they appeared at a height of 1 m as we ascend.
7- The distance between the house and boundary wall to the north and south directions should be 3 m or more to ensure the natural ventilation of the house and access of the air in internal spaces.
8- At the height of 10 m, it noted that the wind speed ranged between 3.4 m/s to 4.5 m/s, higher than the speed in the same area and only in the height of 1m and 1.5m.
9- The eastern and western corridors affect wind speed in the area between house and boundary wall to north and south, where the wind speed increases as the width of the corridor increase. This type of arrangement is strongly accepted for residential areas.

7.11.4. Results obtained from the second model

1- In this model wind speed varies between 2.5 and 2.8 m/s within the residential area.
2- The direction of the wind changes to east and west on the streets heading to east and west, because it collides with row of houses.
3- The wind speed in the north and south streets is higher than the speed inside the houses.

4- The wind speed in the side corridors of the buildings varies between 2.5 m/s and 2 m/s . This means that it is higher than the wind in the courtyard behind the houses where speed is between 1m/s to 0.5 m/s.
5- The wind speed is lower in the rows of houses located behind the first row.
6- Wind speed increases from 1.5 m/s to 3.5 m/s when it crosses the open space with 100 m width.
7- At the height of 7.5m, the first row of one-story houses has no effect on the rows of the houses next.
8- Wind speed is affected by the open spaces, since the wind speed increases when it crosses the open spaces. Where the appropriate width of the open space is not less than 100m.
9- Tallest buildings block the wind to reach lower one. So the houses must have the same height for the purpose of natural ventilation.

7.11.5. Results obtained from the third model

1- Generally, the wind speed around the buildings ranges between 2.5m/s-0.5m/s, 1m/s – 1.5m/s, 1m/s – 2m/s, and 1.4m/s – 2.4m/s at height of 1.5, 4.5, 7.5, and 10.5 respectively .
2- In the open spaces, wind speed is higher than around buildings.
3- Wind direction changes toward the east and west, in east- ward and west-ward streets because it is affected by the buildings next to the street.
4- Wind speed at the beginning of row houses next the open space higher than speed at the row houses which located before the open space.
5- Wind direction in open spaces is unstable, due to the buildings located behind and in front the open space, Also side streets have effect on it.
6- The wind speed in streets which oriented toward the north and south is higher than in the built- up area.
7- Speed ranged between 2.2m/s and 3m/s in the side corridors of the house

8- Vortexes appeared behind the buildings where the wind scattered in all directions.

9- Speed in the inner courtyard varies between 0.5m/s and 1m/s, lower than speed in the streets.

10- Wind speed at the first row of houses is higher than speed at the following rows.

11- Some wind passes east of the houses area, toward western around the house and then it scatters in different directions.

7.11.6. Results obtained from the fourth model

1- Wind speed around high buildings (four storey) ranges between 3.5 m/s and 1.5 m/s, while around the low buildings (one storey) located behind the high buildings ranges between 0.75 m/s and zero.

2- Wind speed decreases as it heads north toward the low buildings.

3- Wind speed on the northern and southern streets is higher than the speed around the buildings.

4- Wind speed around the high buildings (four storey) is higher than the low buildings (one storey).

5- Wind heads to east and west in streets which direct to east and west ward.

6- Wind speed on the northern and southern streets is higher than the speed around the buildings.

7- There are scattered vortexes and wind in different directions in the inner courtyards of the houses.

8- Triangular shapes area emerges behind the high buildings (four storey), due to the existence of streets on the eastern and western sides. The speed in this area is very low.

9- After the wind crossed the high buildings the wind slightly skewed from north to east and west.

7.11.7. Results obtained from the fifth model

1- The speed of wind varies between 3.5m/s and 4.5m/s around the first row of low buildings. It ranges between 1.8m/s and 2.5/s around the second row of low buildings, and it ranged between 0.9m/s and 1.8m/s around the third row of low buildings where the speed decreases as we head south.
2- Wind speed in open spaces and streets is higher than around buildings.
3- Wind speed around low buildings (one-storey) is higher than the speed around high buildings (4 floors).
4- It is noted that the open space affects the wind speed as the wind speed increase as it crosses the open space, so the wind speed around high houses situated behind the open space is faster than the speed around houses that located before the open space.

7.12. Conclusion

1. For the purpose of training on how to conduct analysis and simulation on the model contains many buildings, a study and simulation on small pilot model with dimensions 4x4x4 m was done by using Ansys 16 CFD. The wind pattern around building is studied, the computational domain, mesh and the boundary conditions was prepared according to the best practice guide lines. Then the simulation and analysis process was conducted and the process reached the solution, but it is noticed that the results are unclear, and the wind pattern around the building hasn't been identified.

2. The second pilot model with dimensions 4x4x4 m was analyzed twice by Ansys 16 CFD. The first time the grid spacing is 0.5 units, and the second time it is 0.1 units. Clear results and diagrams were obtained, showing the movement, speed and direction of the wind around the building.

3. Then five models were analyzed. The wind pattern around buildings was studied and the researcher concluded that the wind speed around buildings is sufficient to achieve natural ventilation, except in low buildings just behind the

high buildings where the wind speed required for natural ventilation in the dry and hot region is 1m/s.

4. The first model was taken from a real area. It consists of 12 houses and oriented to north – south according to the arrangement and planning of the residential areas in Khartoum. The wind speed and direction were plotted at different heights representing the level of windows at different floors. Speed drops to 1.7 m/s in the side corridors after 20 m from the inlet flow and it decreases to 1.2 after 30 m. Vortices appeared on the opposite sides of the wind direction. There is no difference between speed at height of 1.5 m and 4.5 m. Wind direction changed to west and east when it collided with boundary wall or building.

5. The second model is taken from a real third class residential area which located in Al Haj Yousuf - East Nile. The area is planned according to building regulations in Khartoum. The model simulated by using Ansys 16 CFD. The 3 dimensional was prepared by using Auto CAD. Then the computational domain was specified to be 694x613x65 m, and the speed and contours were plotted at different heights, At the height of 1m or 1.5m, the speed varied between 2.5 m/s and 2.8 m/s when it collided with the buildings. The wind speed in the side corridors is higher than in the courtyard behind the houses. At height 4.5m the speed is higher than the height of 2m. It ranged from 1.5 m/s to 5, 5 m/s, at 7.5 m. When the speed is higher than height of 4.5 m, it increases when we get up.

6. Third model is identical to the second one, according to the area, components of the residential area and number of houses, however, it is based on the hypothesis that the all houses have the same height (13m). In this model, wind speed at height of 1.5m, 4.5m and 7.5m ranged between 1.7m/s and 2.4m/s at the beginning of the residential area (first row of houses). It decreased in houses next the first row to come between 1.5m/s and 1m/s. it’s noticeable that this speed is sufficient to provide natural ventilation in the hot- dry regions, where the speed required 1m/s. as for the height of 10.5m. The wind speed around

buildings ranged between 4.5m/s to 5m/s, so the upper floors are the most fortunate in terms of good natural ventilation.

7. The fourth model based on the hypothesis that the southern part of study area consists of four-storey building (13m), while the northern part consist of one-storey houses. The wind blows from south to the north and passes through the high houses firstly then move to the low houses. The wind speed around high houses ranged between .5m/s to 1.5m/s, higher than speed around low houses located immediately behind the high house, where speed ranges between 0.75m/s to zero. Therefore it is important to locate open space to separate between high and low houses so that the natural ventilation will be provided to low houses. The most important observation in this model is the emergence of the triangular area behind the high houses, and that the wind speed in this area ranges between 0.75 m/s to zero.

8. The fifth model is identical to the fourth one. The difference is that the wind blows from north to the south passing through the low houses firstly then move to the high houses. It is clear that the wind speed around low houses is higher than speed around high houses. The open space between low and high houses helps increase the wind speed around the high houses located behind the open pace. At height of 7.5m and 10.5, it clear that low buildings do not affect wind pattern.