Chapter Eight

Conclusions and Recommendations

8.1. Introduction

Natural ventilation is important for healthy living conditions. It helps reduce the use of mechanical ventilation which is harmful to the environment. Wind pattern, therefore should be taken into consideration during physical planning and architectural design process of residential areas.

In the past, the wind speed and direction within the residential areas was measured and determined by complex mathematical equations. Using mathematical equations is a complex method and very difficult and time wasting for reaching solution or resolving equations.

Later, the wind tunnels were used to study wind pattern within urban areas.

Although the wind tunnels are effective way for wind studies, it is very expensive, especially for the simulation of full-scale model.

Now, CFD is used all over the world for the analysis of wind pattern in the urban residential areas in particular.

In this research, Ansys 16 CFD is used to study and analyze the wind pattern. The study aimed to investigate wind pattern and behavior in residential areas to ensure natural ventilation and arrive at guidelines and standards that contribute in planning and architectural design of residential buildings.

This chapter is the sum-up of the findings of this research. The results are related to the wind speed and direction at any point of the residential areas. The findings are also concerned with the distance between houses, which is adequate and necessary for equal and proper ventilation for all the houses.

The results also focus on the internal courtyard between the built area and the boundary wall and its effect on the circulation of wind and the importance of open space within residential areas for accelerating wind speed.

This chapter is a review of the final findings and conclusion of the research. The research has come up with findings related to urban planning and architectural design of the residential areas, especially third-class.

This chapter also discusses recommendations and proposals necessary to activate wind pattern that achieves natural ventilation in the residential buildings.

It has also come up with proposals for studying wind pattern to ensures natural ventilation in residential buildings and help researchers go further for investigating some areas related to the current research

8.2 Methodology

This part reviews the methodology used to find out the results of the research. The research started out by investigating the elements of climate, wind pattern and the effect of these factors on wind movement in urban residential areas. The tools used in wind studies and wind pattern include wind tunnels and CFD. The latter is a powerful tool for the analysis of wind around the buildings. It is available, easy to use, accurate, precise and less costly compared with wind tunnels.

The CFD application in urban wind studies and wind pattern were discussed to base a theoretical and practical background about CFD technique and to understand the simulation process for wind pattern around buildings.

The study also reviewed the CFD use for analyzing the case study and wind pattern around buildings in urban areas. The research has specified and studied the study area which lies in central Sudan. The study area is characterized by a hot climate. The population, the social and economic situation and the climate conditions were also discussed.

Wind pattern within a real residential area is studied and simulated to know the wind behavior, speed and trends within the area provide natural ventilation to all houses. Wind pattern was analyzed in five models and results were reached in chapter Seven.

8.3. Conclusion

Before conducting the analysis of the models, two small pilot models with dimensions of 4x4x4 m (single building) were analyzed. The models aim to train on how to conduct analysis and simulation on the models which consist of many buildings.

Then the study examined wind pattern around the residential buildings by using five models taken from the study area. The first model is a small residential area consisting of 12 houses. The second model consists of 242 houses, 90% of houses are 4m high. The model is taken from Al Haj Yousuf, Block 10, Khartoum State. It represented the existing situation of the area. The third model is the same as the second one, but it was assumed the four-storey buildings (13m), had already been constructed according to the building regulations of the third class area.

The fourth model is the same as the second. However, the southern part of the study area was assumed to draw four-storey buildings. The northern part of the area under study consists of single story buildings where the wind blows from the south to the north. The fifth model is typical to the fourth one, but was assumed that the wind blows from north to south.

Analyzing the wind pattern in the five models, the researcher has arrived at the following conclusions.

1. Wind speed achieves natural ventilation in the study area, where the required wind speed is 1m/s.
2. The upper floors have distinguished access to wind in terms of better natural ventilation.
3. When a low building is located on the western or eastern side of a high building, it is noted that the wind speed behind this building is higher than the speed behind the low buildings adjacent to high buildings from the south or north side.
4. The wind speed decreases 75% when it collides with a building. Then it scatters to top, bottom or two sides of the building.
5. Vortexes appear behind the building in the opposite direction of wind with a drop in the speed reaching 80% in this area

6. The wind returns to its normal speed after 48 m behind the building. (12 times the building height).
7. Open spaces affect wind movement, as the wind crosses the open spaces, the speed increases.
8. The streets heading south and north are affected both the speed and direction of the wind.
9. The speed of wind in the first and second rows of houses is higher than the row next. The speed decreases as we deepen in the residential area, while the wind speed around the buildings ranges from 0.75m/s to 1.5m/s.
10. When the wind speed was read within the residential area at height 1.5m, 4.5m, 7.5m and 10.5m, it was found that the speed has increased as we go up.
11. The wind direction changes to the east and west and top when it collides with the boundary wall. This leads to the emergence of an area behind the boundary wall, where the wind speed varies between zero and 0.5m/s.
12. Vortexes and scattered wind appear in all directions in the internal courtyard of the houses. The speed in these yards ranges between zero and 1m/s. The speed varies from one courtyard to another according to the geometrical shape of the houses and the area of yard.
13. The dispersion of the wind in the area between the boundary wall and the building in first row is consequent of the collision with the boundary wall. Then the vortexes appear in the opposite direction.
14. Wind speed is low (0.5m/s) at height 1.5m in the area between the boundary wall and the second row. The speed increases as we go up and as the area increases.
15. Wind speed in the side corridors of the houses is higher than the speed in the internal courtyards located behind the house.
16. Wind speed in the north and south streets is higher than the speed around the buildings.

17. The speed of wind in the open spaces is higher than the speed around buildings.
18. Wind speed around houses located behind the open space is higher than speed around houses located before open space directly.
19. Wind speed varies from one point to another within the same open space due to the different heights of the buildings located before the open space.
20. Wind speed in the middle of the open space differs from its sides, due to the effect of wind coming from the streets around the open space.
21. When the width of the open space, lying in the middle of the houses, is wider the wind speed increases around the buildings situated next open space.
22. The geometric shape of the house affects the movement of wind around the building. For example, when all the buildings have equal heights (four storey), the wind speed around the buildings varies between 2.5m/s and 0.5m/s.
23. In the case of equal buildings (four storey), the speed of the wind in the open space is higher than the speed around these buildings.
24. The wind direction is skewed to the east or west in the streets heading from the east to west because it collides with buildings lying next to these streets.
25. Wind speed on the streets heading north and south ranges from 4.5m/s in the area with one-storey buildings, while the wind speed varies from 3m/s to 4m/s in the streets of the four storey buildings.
26. Wind speed in the side corridors of the high buildings (four storey) varies between 2.2m/s to 3m/s. That means it is higher than the wind speed in the same corridors around the low buildings (one storey), where the speed varies between 1.5m/s to 2m/s.
27. Wind speed in the internal courtyard of the high buildings (four-storey) is less rapid than in the open spaces located in the midst of these buildings.
28. When houses are of equal height (four storey), the speed of the wind in the first and second row is higher than in the next rows.

29. Wind speed on edges of the open space, lying in the middle of high building, s is higher than the speed in the middle of open space due to the effect of the north-to- south streets.
30. When the wind blows from high buildings to low one, the wind speed around the high buildings is higher than the low building.
31. When the wind blows from high to low buildings, a triangle shape behind the elevated buildings can be seen, with speed ranging between 0.8m/s and zero.
32. Wind speed around low or high buildings doesn't vary when the wind blows from low buildings to high buildings.
33. When the wind passes through low buildings, it collides with high ones and it scatters in all directions.
34. When the wind blows from low to high buildings, the speed around high buildings separated from low building by open space is higher than the speed around high buildings adjacent to the low buildings.
35. When the wind move from low buildings to high buildings at height of more than 4 m, low buildings do not affect the high ones.

8.4. Recommendations

Based on the above conclusions, some of the following recommendations are related to the CFD simulation application and the others are related to the urban planning process and the architectural design of residential areas.

8.4.1 CFD Application

The Ansys CFD16 has been most widely applied to study wind pattern around buildings for different purpose especially natural ventilation studies. For the analysis of any model studying wind pattern around buildings, the following steps should be followed:

1- Advanced computer required for simulation.
2- Three dimensional models should be prepared by Auto CAD or other related software and converted to Ansys CFD.
3- Three dimensional models should be simple and without details

4- The mesh should be chosen with small distances (0.1 units) for example.
5- Converting the model into simulation program for example Ansys CFD.
6- Generation of computational domain.
7- Generation of the computational grid.
8- Specify the governing equations and all other parameters (velocity, direction, temperature).
9- Run process.
10- Analysis and summarization.

8.4.2 Planning and Architectural Design Process.

1- It is preferable to design the residential buildings in the form of square or rectangle, and avoid the U or Z shapes so as to minimize the generation of vortexes and scattered wind in the small yard.
2- If a low building is adjacent to a high one, it should be located on the east or west side of the high building. Accordingly, the wind speed will increase behind the low building.
3- When all the houses are of equal height (one storey), the open space must be 70 m wide at least, and separate each four or six rows of houses at the most.
4- When the building is composed of four storeys, the width of open space should be at least 100m wide and separate each four or six rows of houses at the most.
5- If there are low buildings next to the high ones, they should be separated by open space with 100m width at least equal to the length of the high buildings.
6- Low buildings will not be located in the triangular area that appears behind the high buildings.
7- The width of open space separating high and low buildings is equal to the length of the row of high buildings, and is less from both sides, so the open space takes the triangle form after 100m.

8- Whenever the distance between the building and boundary wall is greater than 2.5 m or more from the north or south side, the wind speed exceeds 0.75 m/s in this area. This means possible natural ventilation for the buildings.
9- Increase the streets width, which are east and west ward to more than 15m so as to reduce the vortexes and scattered wind that stir dust and dirt.
10- Reduce the width of the streets which are directed to the north – south, to 15m or less to help increase wind speed.
11- In case of low-lying buildings (one storey) behind the high buildings, it is better to place low buildings around the open space in a triangular shape.

8.5. Further Research in the field

Finally the researcher recommends the following area for further investigation.

1- Wind movement in the residential areas for purpose of providing natural ventilation, especially third class districts.
2- Studying wind pattern in the streets of residential areas to explore the effect of the street on the natural ventilation inside the houses.
3- Wind movement in the internal courtyards, and its effect on the natural ventilation.
4- The effect of boundary wall height on natural ventilation.
5- The effect of streets width on wind movement.