Analysis and Improvement Strategy of Winter Monsoon Environment of Courtyards in Villages and Towns of Cold Areas

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Abstract
There is piercing wind blowing in rural settlements of cold areas during winter time, not only affecting the residents' outdoor activities, but also resulting in negative impacts on building energy efficiency and indoor thermal environment. As courtyard is the main space for outdoor activities of rural residents, whether its wind environment is good or not will directly influence people's life quality and productivity. Through visit and investigation about courtyards of Wudalianchi in Heilongjiang province, China, this paper has summarized components and layouts of courtyards in this area, using Fluent to make a simulation analysis of wind environment with different layouts. It also takes rural residents' activity type and region in the courtyard during winter into consideration, analyzing the influence winter monsoon environment in various courtyards has on people's activities and coming up with the corresponding improvement strategy of design.
Keywords: NORTHEAST CHINA, COURTYARDS IN VILLAGES AND TOWNS, LAYOUT, WIND ENVIRONMENT

With the fast economic development in rural areas and the improvement of peasants' living standard, people have paid more and more attention to the comfort and livability of the living environment. Due to the influence of climatic characteristics, layout features and so on, there is usually piercing wind during winter in villages and towns. The outdoor wind environment has always been the weak point in village and town construction, which not only directly affects residents' outdoor activities, but also has certain negative impacts on building energy efficiency and indoor thermal environment. The field research and testing of villages in Wudalianchi, Heilongjiang province show that 78.3% of the interviewees think the wind environment in courtyards during winter has large influence on outdoor activities.

1. Main Elements of Courtyards in Villages and Towns

The main elements of courtyards in villages and towns can be divided into element of production, life and landscape according to their functions. Element of production mainly includes barn, vegetable garden, livestock shed, garage, storehouse of agricultural machinery, etc., with barn and vegetable garden take large proportions in usage, being respectively 34% and 33% in the overall functional element of production; element of life mainly includes main house, dry pail latrine and leisure space in the courtyard; element of landscape mainly refers to garden, pavilion, vegetation and so on inside the courtyard as shown in Figure 1.

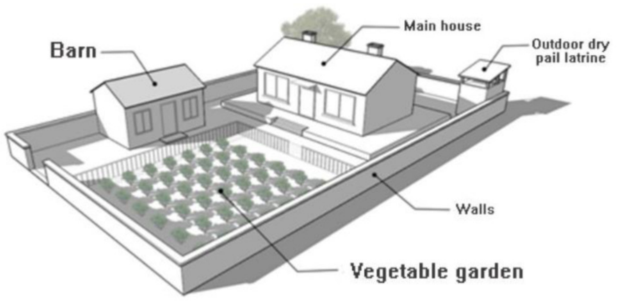


Figure 1. Diagram of Main Elements of Courtyards

(1) Main house, the primary place for peasants to live in, is the core area of the courtyard. Houses in this area are mainly of three bays, about 10m long, 6m wide and 4.5m high as shown in Figure 2.

Figure 2. Real Scene Picture of Main House

(2) Barn is the additional room in the courtyard mostly used for storing tools and sundries. It is often located near the main house in order to shorten the traffic streamline distance and make it convenient for peasants to reach the tools, being about 6m long, 4m wide and 2.5m high. Based on the positional relation between barn and main house, the courtyard's layout can be mainly categorized into four types of courtyard, horizontal line-shaped, L-shaped No.1, L-shaped No.2 and U-shaped one as shown in Figure 3.

(3) Vegetable garden mainly produces economic crops such as green stuff for peasants to eat. They are mostly herbaceous plants---eggplant, pepper, cabbage and so on, with the height of about 0.5m. There are also corn and soybean, shorter than 1.5m.

(4) Outdoor dry pail latrine is still used by most families in rural Northeast China at present. It is about 2m long, 1.5m wide and 2m high, usually located in the corner of the courtyard, mostly being a downwind place of the courtyard because it is easy to produce an offensive odor.

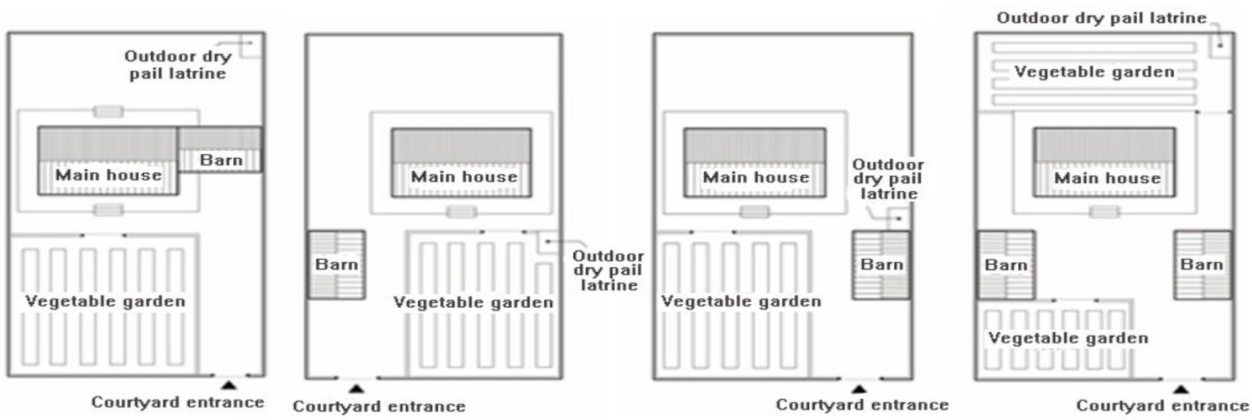
2. Simulation and Analysis of Wind Environment in Courtyard

The issue of winter monsoon environment in cold areas centers on wind protection, which is mainly of trying to prevent cold wind with a high speed or non-uniform wind field from making residents feel uncomfortable. The research has shown that within distance of less than 2m, average wind speed can change 70%, then people's ability to adapt to wind will be largely reduced[1]. Therefore, the key point of this problem is to find out the threshold between area of high wind speed and area of high-low speed among wind speed distribution in courtyard during winter.

3. Model Building

(1) Mathematical model: this paper chooses the improved k-ε model, also called RNG k-ε model to study the distribution of airflow under the circumstance of building blocking. Related researches have shown[2] that RNG k-ε model is good at numerical prediction and able to basically reflect the complex flowing property of the typical flowing-around in bluff-body structure.

(2) Geometric model: in consideration of primary factors affecting wind environment in the courtyard,



(a) Horizontal line-shaped courtyard (b) L-shaped No.1 courtyard (c) L-shaped No.2 courtyard (d) U-shaped courtyard

Figure 3. Layout Diagram of Courtyard

this kind of model is built meanwhile simplifying the courtyard, only keeping main house, barn and walls, with main house's dimension being 6m×10m×4.5m, barn's dimension 4m×6m×4m and walls' height 1.5m. Figure 4 is the simulation model diagram of courtyard (taking U-shaped courtyard for example).

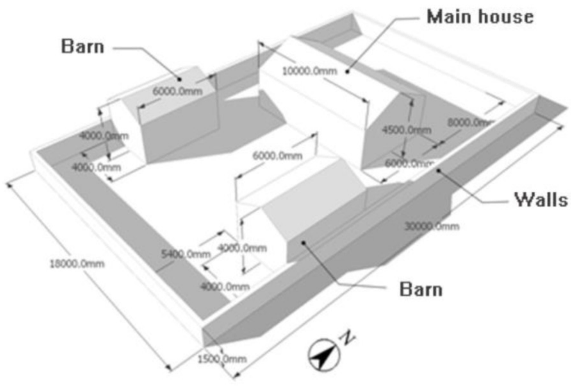


Figure 4. Simulation Model Diagram of Courtyard

4. Computational Domain and Meshing

In order to obtain good simulation effects, reduce the influence boundary conditions of simulated domain have on buildings and create an outdoor open space nearly the same as the atmospheric boundary layer, we have made outdoor wind field's windward direction 5 times the length of the courtyard and downwind 10 times of it, the wind field 5 times the height of the main house[3]. The type and quantity of grid have direct influence on the accuracy of simulation results. As houses in villages and towns are mostly pitched roof style, watershed interface and building surface use triangular unstructured grid cell and body grid mainly adopts tetrahedral one, some specific parts allowed to be cone or wedge shaped, namely TGrid. Since certain areas surrounding the buildings are the primary regions to study wind environment, areas near architectural walls are divided into dense grids while bounds of area are divided into sparse ones, which has formed a grid structure of inside denseness and outside sparseness.

5. Boundary Conditions

(1) Choice of wind direction: Wudalianchi is located in northern Heilongjiang Province, Southern Heihe City, the geographic coordinates of which are 48°30′- 48°51′north latitude and 126°00′- 126°25′east longitude. It belongs to continental climate of cold temperate zone with cold and long winter and short summer. As northwest wind dominates in winter, this paper chooses this type of wind as boundary condition to make analysis.

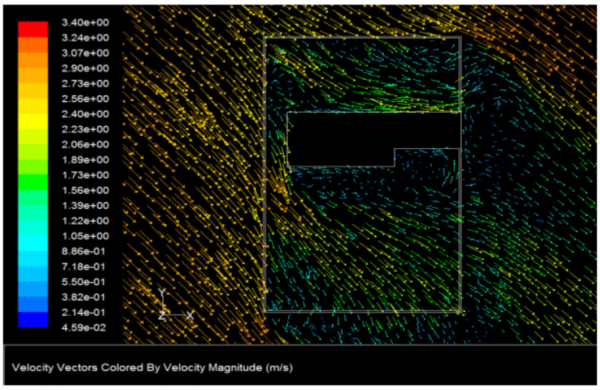
(2) Inlet boundary condition: we choose velocity-inlet boundary condition. With research object (the whole courtyard) immersed in the atmospheric boundary layer, the movement of mechanical turbulence and thermal circulation being weak, parameter of wind speed elevation is set as 0 and wall surface wind speed is ignored. We specify the index of the wind profile through UDF and set the wind speed to 3.0m/s at the height of 10m based on the statistical analysis of average wind speed in winter for years of Wudalianchi.

(3) Outlet boundary condition: we choose pressure-outlet boundary condition, which provides a great solution for the convergence difficulty of back blow export. The given air-current intensity is 2% and viscosity ratio is 5.

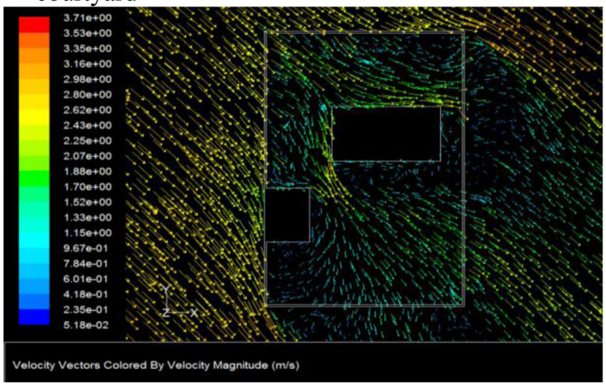
(4) Solid wall boundary condition: because of the selected large computational domain, air flow of the upper side and both sides of the wall almost not being affected by the building and flow velocity in horizontal direction, we deem the gradient along the tangential direction of velocity to be zero and value along the normal direction also to be zero. So wall boundary condition without slippage is adopted. The k-ε model applies to fully turbulent region within certain distance of wall, but it has to be improved due to the larger influence of laminar viscous effects near solid walls such as building surface. Wall-function method is used to modify building boundary areas.

6. Simulation Result Analysis

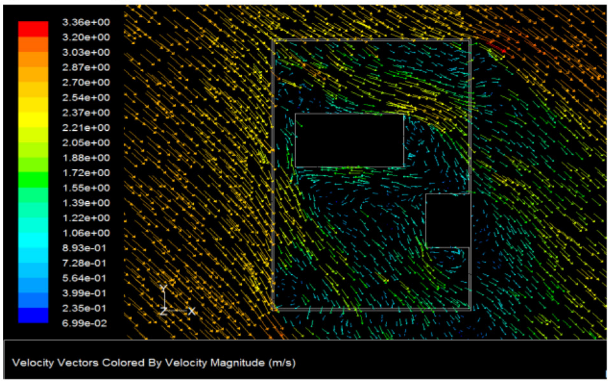
Simulation results of wind environment are shown in Figure 5. On the whole, the speed of the wind between windward buildings and walls is high, but there are obvious differences among wind distribution of layouts in various courtyards. In Horizontal line-shaped courtyard, gable wall on the west side of building is affected by corner wind, so the wind speed there increases and speed ratio is about 1.13, which forms a high speed wind belt, directly impacting the whole courtyard in front of the whole house; a wind shadow zone is formed in the front side of the building with the wind speed ratio of 0.19. In L-shaped No.1 courtyard, since the barn on the left side is blocking the way, high-speed flow only appears in the corner of building's windward side with the wind speed ratio of 1.03 and a little airflow enters inside the courtyard; a wind shadow zone is formed in the lee side of the main house and barn with the wind speed ratio of 0.14. In L-shaped No.2 courtyard, it is easy to have wind effects of narrow path and low-speed eddy current for the main house stands near the left wall with the wind speed ratio of 0.92. Besides, the blocking effect of the main house towards windward flow decreases, making a corner wind formed on the upper right corner of the main house with the wind speed



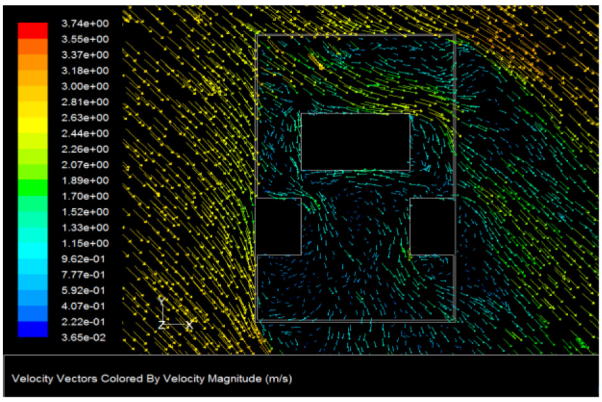
(a) Wind speed distribution in Horizontal line-shaped courtyard



(b) Wind speed distribution in L-shaped No.1 courtyard



(c) Wind speed distribution in L-shaped No.2 courtyard



(d) Wind speed distribution in U-shaped courtyard

Figure 5. Wind Speed Distribution of Layouts in Various Courtyards

ratio of 1.07; a wind shadow zone is formed in the lee side of the main house with the wind speed ratio of 0.09. In U-shaped courtyard, with the increase of the enclosure degree, high-speed airflow that has entered the courtyard disappears gradually and the attenuation of wind speed inside the courtyard increases; a wind shadow zone is formed in the enclosure area of the main house and barn with the wind speed ratio of 0.11. However, there gradually occurs low-speed eddy current as the enclosure degree enhances. Comparative results of various layouts in the courtyards are shown in Figure 6. Maximum wind speed ratio and wind shadow zone area are used as two evaluating indicators and the qualities of wind environment in different courtyards from the superior to inferior belong to L-shaped No.1 courtyard, U-shaped courtyard, L-shaped No.2 courtyard and Horizontal line-shaped courtyard respectively. But wind environment of various layouts in courtyards is largely related to the location of the main house and barn in courtyard as well as space between walls. The environment qualities can all be altered through proper changes.

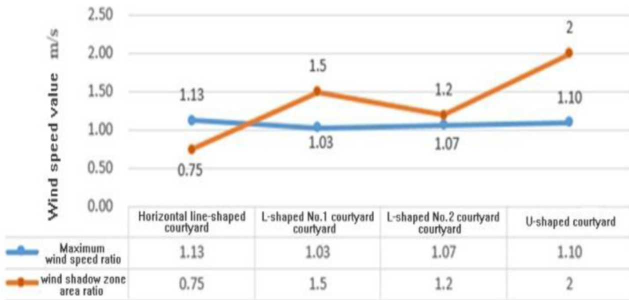


Figure 6. Comparison of Wind Environment in Courtyards with Various Layouts

7. Comfort Degree Analysis and Improvement Strategy of Wind Environment in Courtyards

A simple objective analysis of the wind speed distribution in courtyards cannot exactly reflect the influence wind environment has on residents' life. For example, some regions in courtyards where residents don't frequently do outdoor activities may have hign-speed wind. Therefore, when analyzing wind environment, the primary regions in courtyards for residents to have activities during winter should also be taken into consideration, focusing on solving the unfavorable wind environment problems in these regions.

8. Analysis of Active Regions in Courtyards

As is shown in Figure 7, rural residential courtyards have dual functions of production and life and people's activity type in the courtyards changes with seasons. In summer, people are mainly engaged in farm work such as planting vegetables and have other activities in courtyards like going to the toilet, enjoying the cool air, drying clothes and doing exercise, among which the former four activities each account for more than 70%, while doing exercise takes a small percentage with only 4%. In winter, people's outdoor activities are greatly reduced due to harsh weather conditions outside. They only do some necessary daily things such as farming and going to the toilet, but the percentage drops. Figure 8 shows areas of activities when people doing the above two things in winter (including paths and regions). Blue zone represents toilet regions while yellow zone represents farming regions. According to the characteristics of farming in winter, most routes are between the main house and barn, with active regions around the barn.

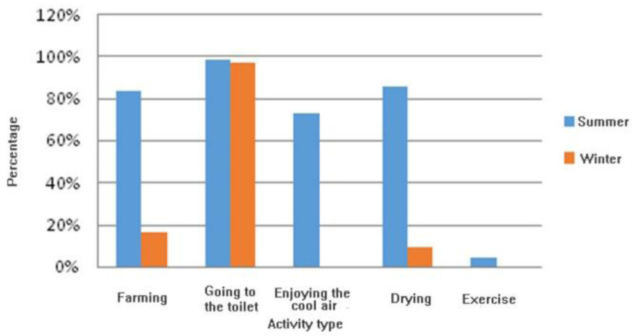


Figure 7. Percentage of Residents' Activity in Courtyards during Summer and Winter

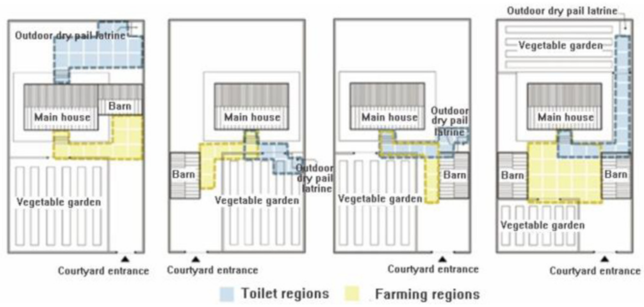


Figure 8. Diagram of People's Active Regions and Paths in Courtyards during Winter

9. Wind Environment's Influence on People's Activities and Corresponding Improvement Strategy

As is shown in Figure 9, the courtyard is divided into grids of 2m long and 2m wide. We have figured out the wind speed values at the grid intersection based on simulation results of wind environment, and broken down these values into x-axis and the y-axis direction. Average wind speed change rate is drawn from comparison of the adjacent intersections' wind speed values on these two directions and regions where people feel uncomfortable caused by wind speed can also be presented as shown in Figure 10.

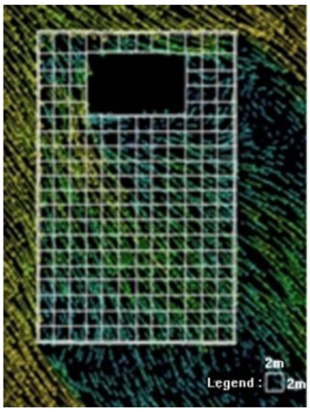


Figure 9. Diagram of Grids

In order to reflect the influence wind environment in courtyards has on people's outdoor activities in an intuitive way and take people's active regions during winter into consideration, we have made Figure 8 and 10 added together to get the diagram of regions affected by wind speed in courtyards with various layouts shown in Figure 11. Red zone represents wind regions where people will feel uncomfortable, purple zone represents regions where people feel uncomfortable due to wind speed when going to the toilet and orange zone represents regions where people feel uncomfortable due to wind speed when doing farm work.

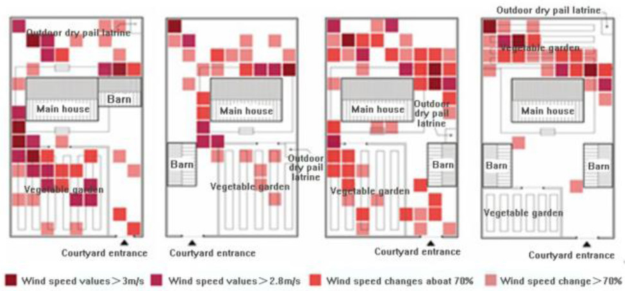
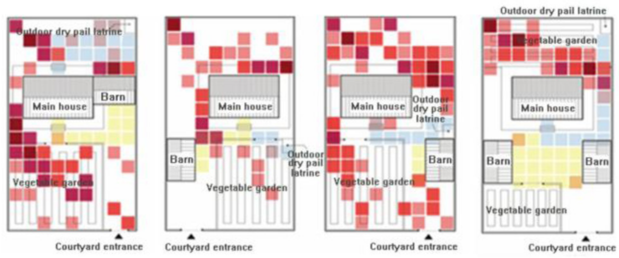


Figure 10. Wind Regions Where People Feel Uncomfortable



(a) Horizontal line-shaped courtyard
(b) L-shaped No.1 courtyard
(c) L-shaped No.2 courtyard
(d) U-shaped courtyard

Figure 11. Diagram of Regions Affected by Wind Speed in Courtyards with Various Layouts

(1) Horizontal line-shaped courtyard. As is shown in Figure 11(a), there are large wind zones in this type of courtyard making people uncomfortable, accounting for about 36.8% of outdoor courtyard area, but it only has a few overlapping portions of the residents' active regions. There is merely one suqare in the orange zones, showing that when going to or coming from the barn, the residents will feel uncomfortable caused by cold wind in the region 2~4m away from the main house entrance, but they won't be affcted by cold wind when doing farm work around the barn; there are relatively more purple zones, mainly located in the areas on the way to and around the dry pail latrine. As is shown in the figure, the left side (west side) of the dry pail latrine exist uncomfortable wind zones, so designers of the dry pail latrine had better put the entrance on the south side to avoid regions with poor wind environment. In addtion, they can increase the distance between windward walls and buildings to get rid of the impacts brought by the high-speed wind belt.

(2) L-shaped courtyard. It is divided into two types–barn on the left side of the main house and the opposite one, as shown in Figure 11 (b) and (c). When the barn is on the left side of the main house (L-shaped No.1 courtyard), the uncomfortable wind zone is smaller than that when the barn is on the right side of the main house (L-shaped No.2 courtyard), taking up about respectively 24.6% and 42.1% of the outdoor courtyard area. It can be seen that windward barn (on the left side of the main house) is able to effectively block the air flow and weaken the cold wind, but under this situation, the corner wind appearing on the lower left side of the main house will impact residents' farming activities. Therefore, the distance between the main house and the barn should be at least 4m to ensure that residents have a more comfortable production environment. Though there are larger uncomfortable wind zones in L-shaped No.2 courtyard, they don't overlap with people's active regions much. The fact that people feel uncomfortable due to the wind speed within 2m of the main house entrance is related to the small space between the house and the west walls, which can be improved by enlarging the distance between windward houses and walls.

(3) U-shaped courtyard. As is shown in Figure 11(d), the uncomfortable wind zone in this type of courtyard is the smallest among the four courtyards with different layouts, accounting for about 22.8% of the outdoor courtyard area. However, on the way people go to or come from the dry pail latrine, there is uncomfortable wind zone at a range of 6m, which can be solved by changing the location of the latrine. It should be on the downwind side of the summer prevailing wind direction for it will produce terrible odors, which is presented in Figure 11(b).

In addition, the issue of high-speed wind belt easily appearing in windward side of the courtyard can be regulated by making rational distribution of greening. As in shown in Figure 12, leafy trees may be planted on the windward side as windbreaks, which not only can effectively reduce wind speed and wind pressure on the windward side of the building, but also improve microclimate environment and comfort degree of residents' outdoor activities, reduce interior heat loss caused by cold air infiltration as well as convective heat transfer with the purpose of reducing energy consumption. In consideration of actual conditions and people's preferences of courtyards in villages and towns of cold areas, economic plants such as low fruit trees can be planted on the windward side of the winter prevailing wind direction, as long as the distances between trees are properly arranged.

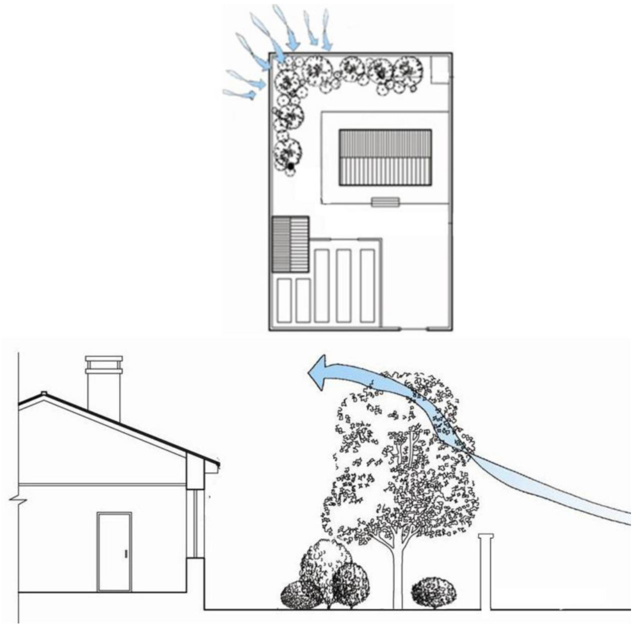


Figure 12. Diagram of Vegetation's Layout and Wind Blocking Effects in Courtyards

10. Conclusion

From the perspective of wind distribution, the wind blocking effects of L-shaped No.1 courtyard and U-shaped courtyard are superior to L-shaped No.2 and horizontal line-shaped ones, which is to say that the higher enclosure degree of windward buildings is, the larger the wind shadow zone inside and the better the wind environment in the courtyards will be, thus providing residents with great outdoor activity space. However, it is easy for low-speed eddy current to appear inside the courtyards, which can result in garbage accumulation and damage the sanitary environment. From the perspective of wind environment's comfort degree, L-shaped No.1 courtyard and U-shaped courtyard have smaller wind zones that make people uncomfortable. But when combined with people's primary active regions in courtyards during winter, uncomfortable wind zones of horizontal line-shaped, L-shaped No.1 and No.2 courtyard have fewer overlapping portions of the residents' active regions and high-speed wind zone won't make a big difference on people's daily activities. In conclusion, L-shaped No.1 courtyard has the best layout, while other layouts can be improved by adjusting the distance between buildings and walls or making rational distribution of greening. Ventilation in summer should also be taken into account with the issue of wind blocking in winter.

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