12 Coupling occupants' behaviour and natural ventilation potential analysis in the design of a Chinese rural house

12.1 Introduction

In chapter 11, the VGA analysis method proposed by the author was used for the evaluation of the layout designs of Chinese rural houses proposed by the local government. Type 10 was selected as best design type, because it can most easily achieve thermal summer comfort for occupants in passive ways. The optimised layout has a high potential to achieve natural cross-ventilation, especially in the public spaces, which are important for the local occupants' thermal summer comfort in hot and humid climates. Chapter 11 also shows occupants' movement behaviour in the spaces. The public spaces in the house are the most attractive spaces for occupants. This is related to the occupants' spatial perception. This helps the occupants to enjoy the natural ventilation in the public spaces because there is a high potential to achieve natural ventilation there.

In this chapter, the optimised layout design of chapter 11 will be developed for a new rural house design in the studied area. The focus of the design is still on the occupants' behaviour and natural ventilation potential with respect to the spatial configuration. This study will demonstrate how to use the VGA analysis method for the optimisation of spatial configuration, coupling occupants' behaviour and natural ventilation analysis to design practice.

12.2 Methods

Firstly, the optimised layout (type 10) proposed by the local government is analysed through the space syntax method in terms of occupants' behaviour and natural ventilation potential. Secondly, the optimised layout is improved to create a better potential to provide thermal summer comfort in the new house design. Other design factors such as site, occupants' demands and function are also considered. Finally, the results of the spatial analysis related to natural ventilation potential are validated through CFD simulation.

12.3 Spatial analysis of the optimised layout design by the local government

12.3.1 Occupants’ movement behaviour

The occupants’ movement behaviour was analysed through the convex map and VGA analysis. The boundary of the analysis is the border of the layout in which the indoor spaces and courtyards are involved. The doors are assumed completely opened so that the occupants can pass through. The windows are assumed closed because they are not for occupants’ movement. Figure 12.1 shows the optimised layout of the rural house and the results of the behaviour analysis. Figure 12.1 (b) shows the function distribution of the spaces. As we can see, the traffic space and public spaces are set at the middle of the layout, and the private spaces are set on both sizes around the public spaces. This gives the bedrooms and bath room good privacy. The living room, which includes the dining room, shows a high connectivity and visual integration value (figure 12.1 (c)(d)(e)). That means it is the centre of the other spaces. The occupants perform most of their activities in the living room. However, there are two main disadvantages that need to be improved. Firstly, a part of the traffic spaces is included in the living room (figure 12.1 (b)). It influences the use of the living room. Secondly, there is only one public indoor space (living room) and one public outdoor space (courtyard). There is a lack of spatial diversity.

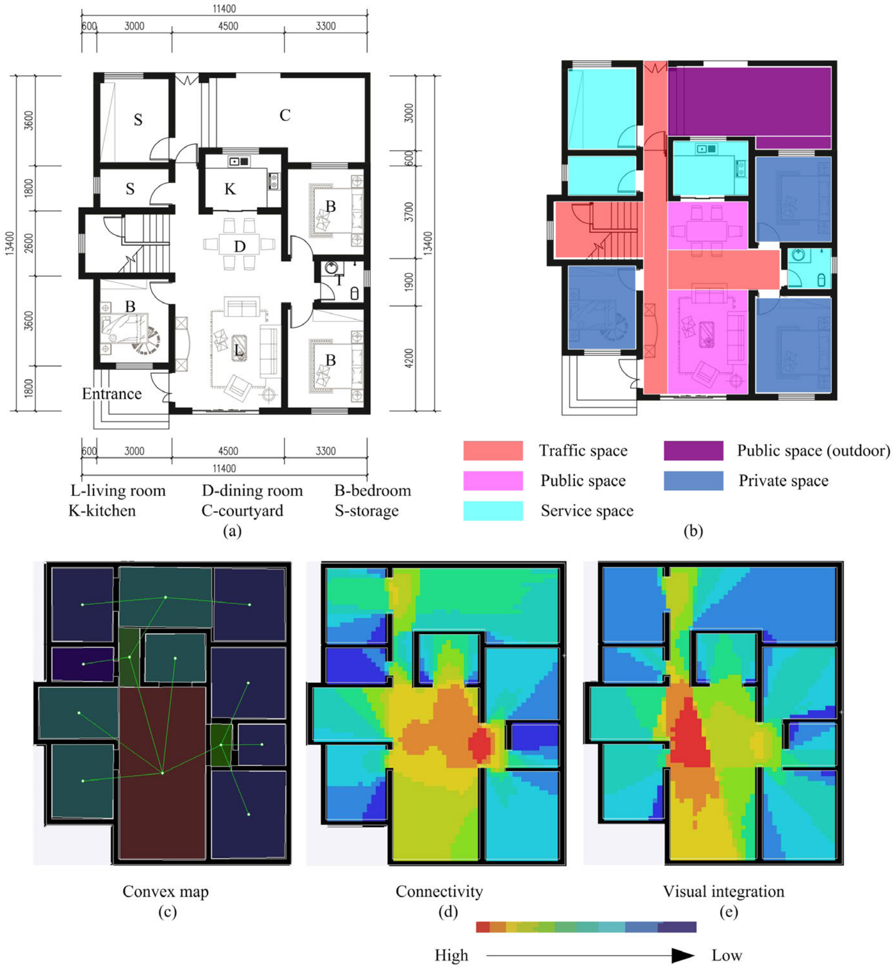

FIG. 12.1 The optimised layout of the rural house and the results of the behaviour analysis.
(a) optimised layout; (b) functional analysis; (c) convex map; (d) connectivity map; (e) visual integration map

12.3.2 Natural ventilation potential analysis

The natural ventilation potential of the spatial configuration was analysed by VGA. In order to involve the outside environment in the analysis, the boundary of the layout was extended to a certain scale, see figure 12.2 (a). In order to reflect the real situation, the wind direction should also be considered in this analysis. It was assumed that the building's main facades with larger openings face the prevailing wind direction to obtain the largest natural ventilation. In the prevailing wind direction, to represent the influence of wind direction in the VGA analysis, the outside environment was extended much farther than in other directions (figure 12.2 (a)). Figure 12.2 (b)(c) shows the connectivity map of the VGA analysis. As we can see, the connectivity value near the windows is higher than in the adjacent indoor spaces. This reflects the real situation that the points near the openings have more opportunities to obtain the outside wind flow. Especially for openings in the prevailing wind direction, the connectivity value is much higher than in other spaces. The rooms that face the prevailing wind direction (the storage room, the kitchen and the bedroom) have a much higher average connectivity value as well (figure 12.2 (c)). The kitchen has the highest. this is because the wind comes from the above, as we assumed. The living room has the second highest connectivity value. This is due to the large openings of the living room. It is also found that the connectivity value of the living room is evenly distributed, but for the rooms on the windward side with a high average connectivity value, the distribution is not uniform. In some of the locations in the rooms, such as the corner near the window, the connectivity value is low. In other rooms, which do not face the wind direction (other two bedrooms, toilet, stair and another storage room), the connectivity value is relatively low.
The VGA analysis shows that the most important public space-living room has a high potential to obtain natural cross-ventilation. The space matches the occupants' movement analysis above in terms of space. The living room is the space with most occupant activity and it has a high potential to achieve natural ventilation. However, some improvements are needed to enhance the natural ventilation potential of the current layout design. The kitchen is close to the living room. The wind has to cross the kitchen and then flow to the living room. This weakens the natural ventilation of the living room. Another is the fact that the depth of the living room is relatively great in the wind direction. This makes it more difficult of wind to pass through the living room.

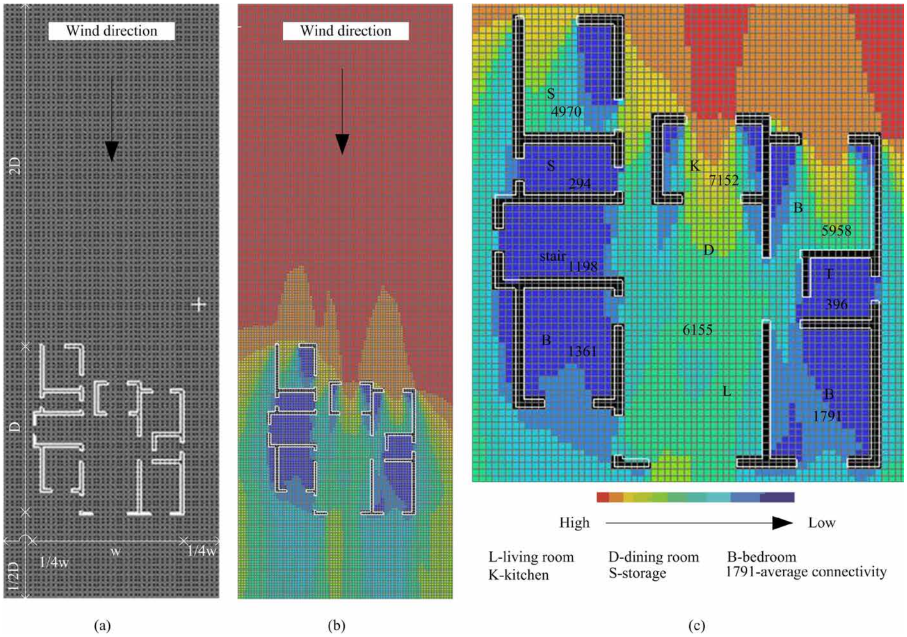

FIG. 12.2 The boundary setting in the VGA analysis (a) and the results of connectivity map (b)(c)

12.4 The new house design

12.4.1 General introduction of the new house design

The site for the house is located in a small village, on a hilly terrain, in a valley in Chongqing (figure 12.3 (a)). The site area is approximately 427 square metres and is surrounded by farmland (figure 12.3(b)). In front of the site (south-west), there is a small lake and behind the site (north-east), there is a small hill (figure 12.3(b)(c)). There are no buildings surrounding the site. The natural environment is good.

FIG. 12.3 Terrain of the site (left), view from the small hill (top right) and view from the lake side (bottom right)

The house owners are a middle-aged couple. Four residents live here: the couple and their old parents. However, there are some temporary residents: their daughter, sisters, brothers and relatives possibly live there for a short period, especially during the holidays. Therefore, the owners request four bedrooms and two toilets. A living room, dining room and kitchen are also necessary. They also hope to have a courtyard. The total area of the house is approximately 200 square metres. Two stories are expected. The residents do not exactly understand passive cooling, but they do hope to reduce the electricity usage in terms of reducing the use of air conditioning in summer. They hope the budget is a maximum of 25,000 euro.

12.4.2 General design process of the layout

The new house design will originate from the optimized house type 10. The layout design of type 10 will be improved for the new house coupling occupants' behaviour and natural ventilation potential analysis for a better thermal comfort. In this case study, only the ground floor will be analysed in detail by the space syntax methods. The layout of the first floor will be designed based on the layout of the ground floor and other functional demands.

Figure 12.4 shows the general design process to create the layout of the new house originating from the initial design. The initial design is the prototype which is created by the designer or existing design. in this case, the prototype is the optimized layout proposed by the local government. The 2nd step is to use convex method to analyse the initial layout. The convex method was chosen for the preliminary analysis of the evolution of the layout because the convex method can reflect the logical relationship of the spaces simpler and clearer, even though the convex map cannot completely reflect the natural ventilation potential for a spatial configuration, as mentioned in chapter 10. In this step, the first is to decode the layout into convex spaces and then build the connections of the spaces which are connected directly. It should be noted that the outdoor environment should be involved which was mentioned in chapter 10. The spatial features in terms of public space, private space, public service space and traffic space are identified. The 3rd step is to identify the core public spaces in the spatial structure. It has been mentioned that public spaces are the most important spaces in the spatial structure because most of the occupants' activities happen there. The occupants' behaviour and natural ventilation potential in the public spaces are the focus in this study. Therefore, identifying the approximate shape and the relationship between the public space and other spaces is an important step in the design process. The 4th step is the evolution of the public spaces and other inter-spaces based on three aspects: functional demands, occupants' behaviour and natural ventilation potential. Step 3 and step 4 are interactive processes. If the public spaces were adjusted in step 4, the public space should be identified returning to step 3. Step 3 and step 4 are the most important steps in the design process. The graphic based analysis is very helpful to the evolution of the design. The 5th step is to identify the approximate shape and location of all spaces after the logical relationship of the spaces is confirmed in step 4. The 6th step is to adjust the location of the openings connecting the indoor and outdoor spaces. The 7th step is to give the actual size and location of the rooms and the openings. The 8th step is to add the semi-outdoor spaces and courtyards to the layout as we clarified that these kinds of spaces are important for the building microclimate in part 1. The 9th step is the evaluation of the new proposed layout design using spatial analysis method which was proposed in chapter 10. The occupants' behaviour and natural ventilation potential are coupled analysed. If the results are better than the initial design, the final design can be proposed. If not, the whole process can be repeat again.

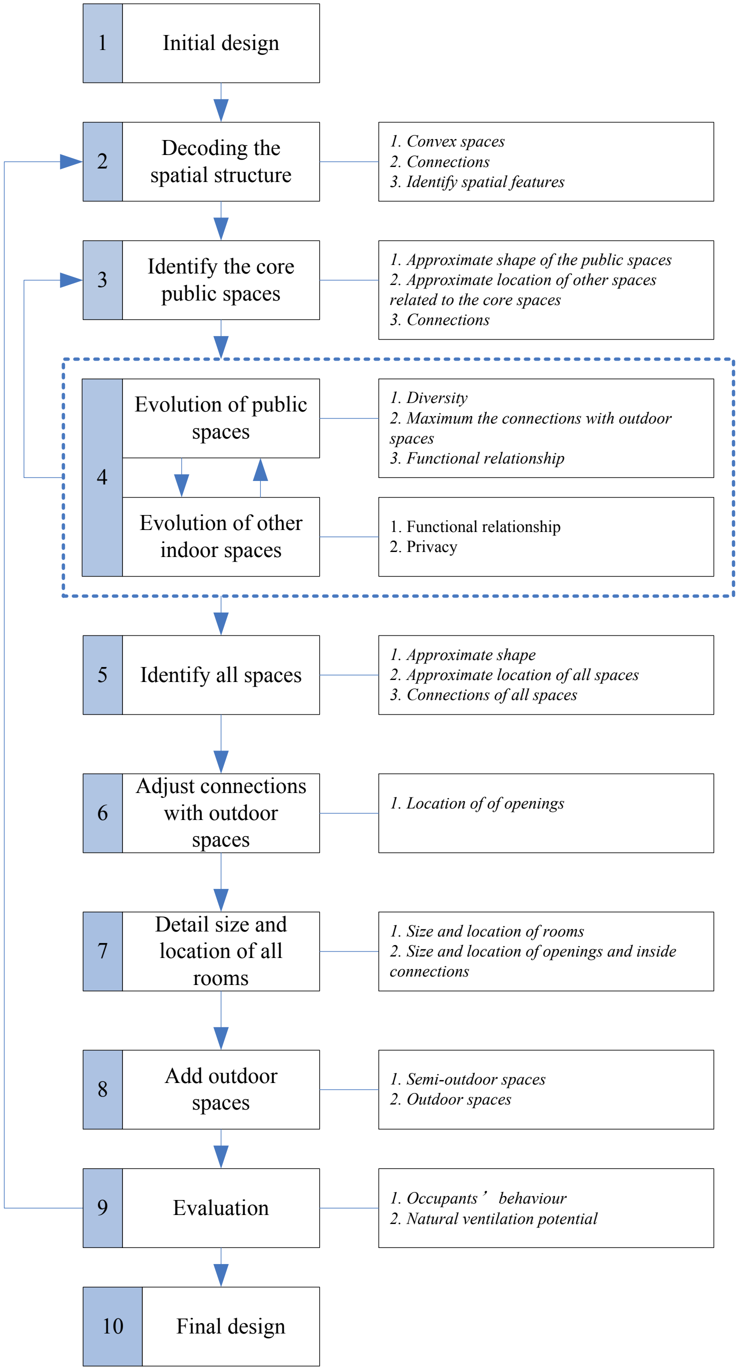

FIG. 12.4 General design process to create the layout of the new house

12.4.3 Evolution of the initial layout of type 10

Figure 12.5 shows the evolution process of the initial layout of type 10, and table 1 illustrated the objectives and actions of each step.

The 1st step is to draw the initial layout of type 10. The 2nd step is to decode the initial layout. The rooms were decoded into convex spaces were represented as nodes, and the outdoor spaces were represented by black nodes. Related spaces are connected with a line. The spaces were classified into public space, service space, traffic space and private space by different colours. The 3rd step is to identify the core public spaces. In this step, a graph shows the first time to identify the core public space. The living room (involve dining room) is the only core public space at the current design. Because rectangle is the most common shape of rooms in architectural design and there is no special demand by the occupant, the public space was identified as a rectangle. The location of other spaces related to the public space was set. The connections of the spaces were represented as lines. The 4th step is the evolution process of the space structure. The first is to satisfy the occupants' demands and improve the diversity of the public space. The storage room and one bed room were replaced by a independent dining room and a patio, see step 4a. After this adjustment, there are three public spaces. Therefore, the next step returned to the 3rd step to identify the newly added public spaces, which was shown in graph 3b and 3c. Both the shape of the patio and the dining room were set as rectangle. The patio was set on the left of the living and the dining room was next to the patio. The entrance was moved to the patio. The next step went to the 4th step again. Graph 4b shows the move of the kitchen from above the living room to connect with the dining room. This is a functional demand. It also makes sure that the living room has more space to connect to the outdoor environment. The spatial structure of the rooms on the right of the living room was kept the original design because the design is good for functions and privacy of the bedrooms and bathroom. After the steps above, the logical relationship of the inter-spaces was confirmed. The 5th step is to identify the approximate shape and location of all spaces. All the room's shapes were set as rectangles. The 6th step is to adjust openings to connect to the outdoor spaces. Two openings were set at above the patio and the living room to enhance the natural cross ventilation. The opening connected to the stair was moved from the left of the stairs to below the stairs. After this step, the logical relationship between the inter-spaces and outdoor spaces confirmed. The 7th step is to specific the actual size and location of the rooms and openings. All three aspects: function, occupants' behaviour and natural ventilation potential should be considered in this step. The living room was deigned more independent and narrower and wider. The openings in the living room were set as large as possible for natural ventilation. The 8th step is to add the semi-outdoor space-veranda in the front of the living room and patio, and on the back of the patio. A front courtyard and a back courtyard were set at the front and back of the layout.

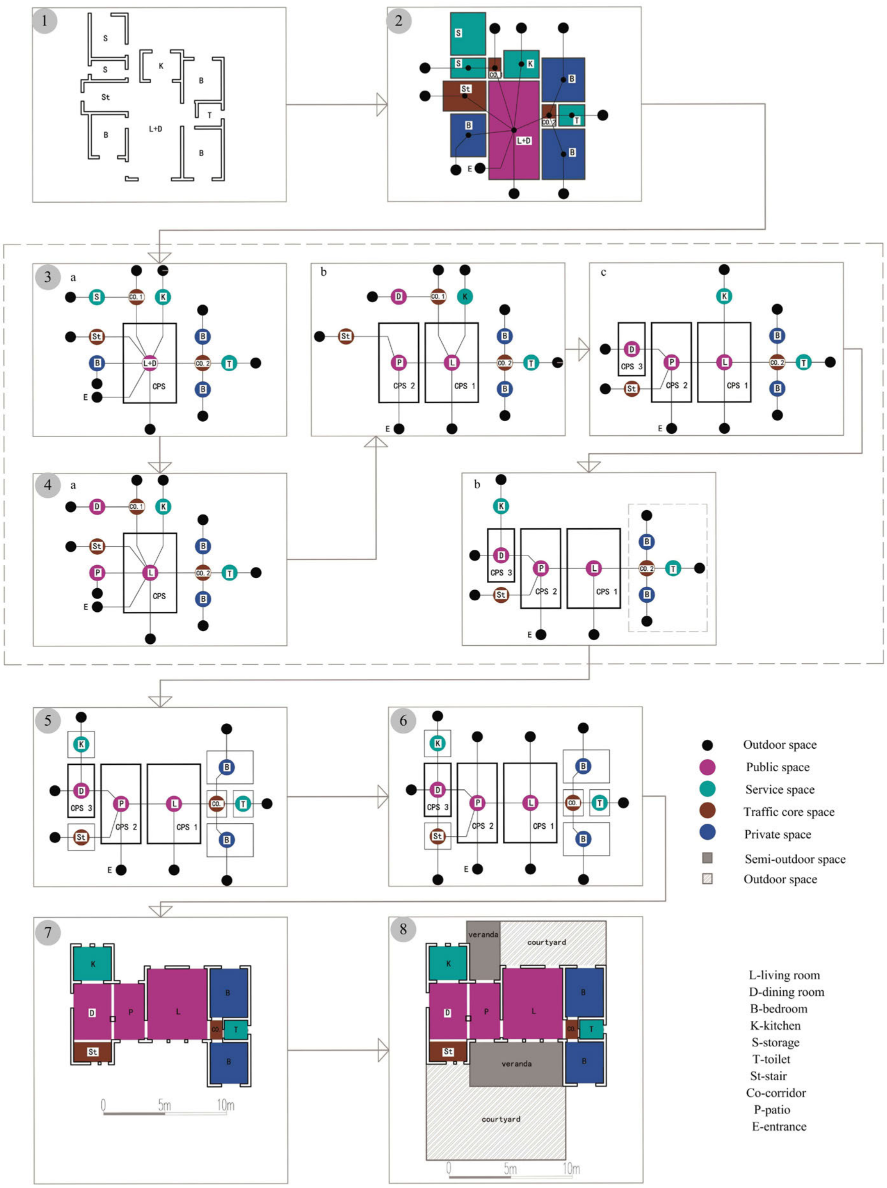

FIG. 12.5 The evolution process of the layout

TABLE 12.1 Objectives and actions of each step of the design process

Steps	Objectives	Actions in detail
1	-	-
2	Decoding the initial layout	1. The layout was decoded into convex spaces and the outdoor spaces were represented by black nodes 2. The connections between the indoor and outdoor spaces were built 3. The spatial features were distinguished by colour
3	**3a** Identify the core public space	1. The living room (involve dining room) is the core public space 2. The shape of the public space is a rectangle 3. The location of other spaces related to the public space were set 4. The connections of the spaces were built
	3b Identify the new public space-patio	1. The shape of the patio is a rectangle 2. The location of the patio is on the left of the living room 3. The entrance is moved to connect to the patio
	3c Identify the new public space-dining room	1. The shape of the dining room is a rectangle 2. The location of the dining room is on the left of the patio
4	**4a** 1. Functional demands 2. Improve the diversity of the public spaces	1. Delete storage rooms and one bedroom 2. Separate the dining room and living room and set the dining room as public space 3. Add a patio as public space 4. The patio took the place of the bedroom and the dining room took the place of storage room
	4b 1. Functional demands 2. Maximum the connections of the public spaces to the outdoor spaces	1. Move the kitchen from the above of the living room and to close the dining room 2. Keep the spatial structure of the rooms on the right of the living room
5	Identify the approximate shape and location of all spaces	1. The shape of all the rooms are rectangle 2. The location is set at the node
6	Adjust openings connect to the outdoor spaces	1. Two openings were set at the above of the patio and the living room 2. The opening connected to the stair was moved from the left of the stair to the below of the stair
7	Specific the actual size and location of the rooms and openings	1. Make living room more independent 2. Make the living room narrower and wider 3. Make the opening larger in the living room
8	Make the space more divers in the building microclimate	1. Add the semi-outdoor space-veranda in the front of the living room and patio, and on the back of the patio 2. Add a front courtyard and a back courtyard
9	Evaluation (see section 12.4.4)	-
10	Final design (see section 12.6.2)	-

12.4.4 Spatial analysis (evaluation) of the new layout design

After the evolution of the initial layout which was described in the previous section, the new layout of the house was proposed (figure 12.6). Consequently, the spatial configuration of the layout can be evaluated through the spatial analysis method in terms of VGA analysis.

FIG. 12.6 The new proposed layout of the house

12.4.4.1 Occupants' movement behaviour

The analysis method is similar to the method described in section 12.3. Figure 12.7 shows the occupants' behaviour features on the ground floor and first floor of the new house. In the convex map, the living room shows a high integration rate. Following are the entrance, dining room, patio and front veranda. In the VGA analysis, the front courtyard and the front veranda have the highest connectivity and visual integration value on the ground floor. Following are the living room, patio, back veranda and dining room, for which the connectivity and visual integration value are high to low. In the private rooms (bathroom, bedroom and kitchen), the connectivity and visual integration are very low. On the first floor, the terrace, corridor and the family room have a high connectivity and visual integration. The alterable space has a relatively high connectivity and visual integration. The bathroom and bedrooms have a low connectivity and visual integration. The results show that the design of the two plans suit the occupants' behaviour well, which means that for their activities in public and private spaces occupants have a good privacy.

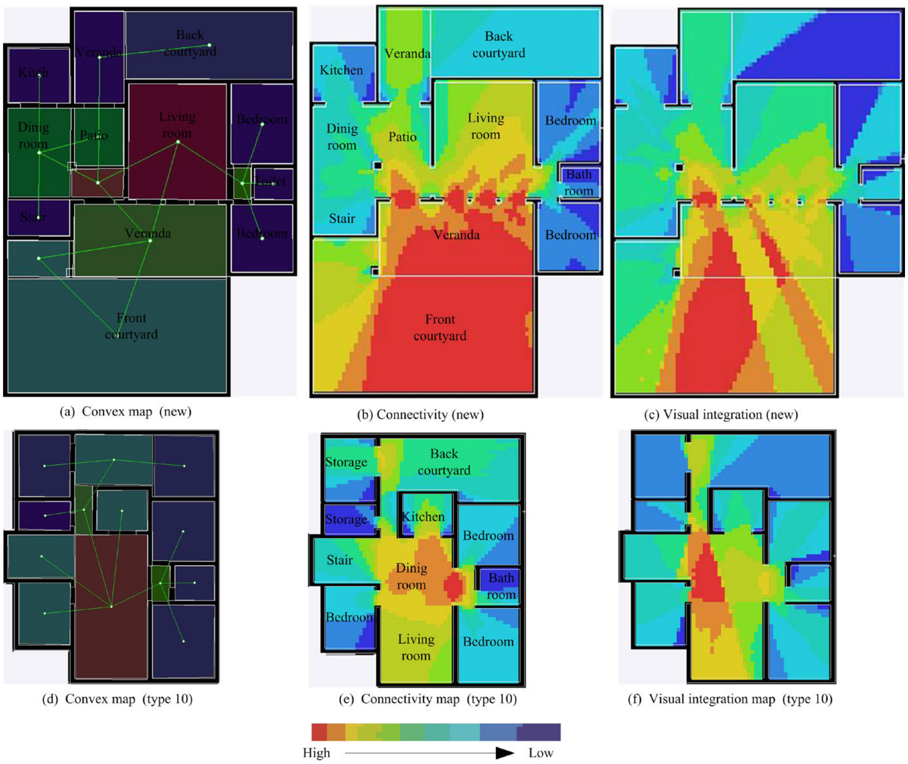

FIG. 12.7 Occupants' behaviour features of the new house and comparison with type 10

12.4.4.2 Natural ventilation potential analysis

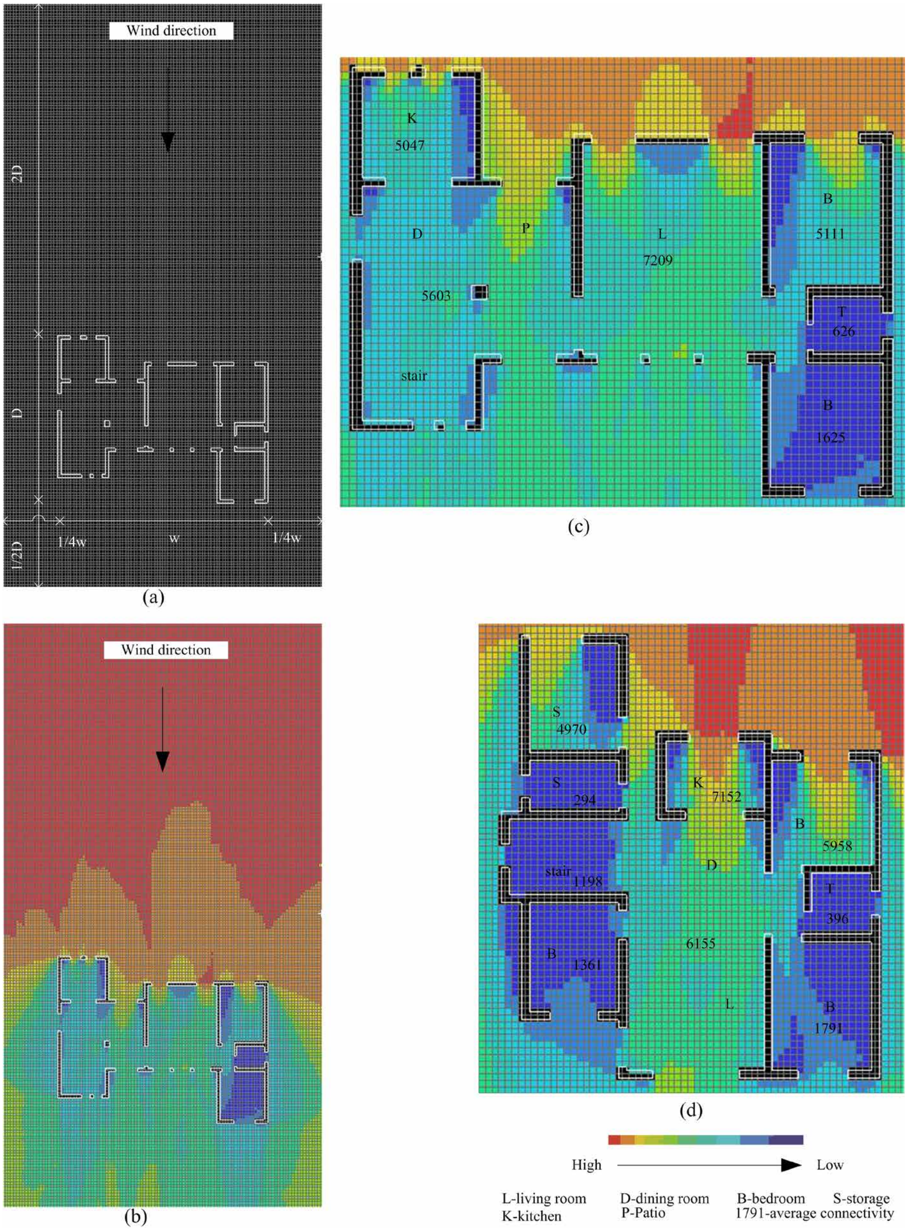

FIG. 12.8 Natural ventilation potential analysis of the new house and comparison with type 10 (a) the boundary setting of the VGA analysis (b)(c) connectivity value of the new house (d) connectivity map of type 10

Figure 12.8 shows the natural ventilation potential of the ground floor. Figure 12.8 (a) shows the boundary setting of the VGA analysis and figure 12.8 (b)(c) show the results for the connectivity value. Similar to the results of the original layout, the connectivity value near the windows is higher than the corresponding indoor spaces. Especially for openings at the above of the layout, the connectivity value is much higher than other spaces. The living room has the highest connectivity value. This is due to the large openings of the living room and the openings directly facing the wind direction. It is also found that the connectivity value of the living room is evenly distributed. The second highest connectivity value is in the space of the dining room, patio and stairs. In the bedroom and toilet, the connectivity value is lower. The results can be matched with the occupants' behaviour analysis, which means the occupants have most of their activities in the spaces with a high potential to achieve natural cross-ventilation.

12.4.5 Comparison of the layout design of the new house and the optimised house

Comparing the results of the spatial analysis of the new house and the original house design proposed by the local government, the average connectivity value in the public spaces of the new house is higher than in the original house. This indicates that the visibility and accessibility of the new house is better than the original house in that the new house has more potential to obtain natural cross-ventilation in the public spaces. The occupants' behaviour fits the air movement behaviour better in the new house than the original house.

12.5 Validation of the spatial analysis through CFD simulation

The correlation between the spatial indicator and the airflow performance were studied in chapter 9. Here, for the rural house design, the spatial analysis method for natural ventilation potential through VGA analysis was validated by a CFD simulation.

The CFD simulation was performed for the ground floor of the optimised local government house and the new house. The ANSYS19.1 program was used for the CFD simulation and the platform of workben19.1was used for the model building, grid setting, parameter setting and post processing. The prevailing wind direction was assumed from the above of the layout, which is the same in the VGA analysis. The local climate data of Chongqing was used for the input. The outdoor wind boundary was set to 50mx50m. The Realised k-e model was used.

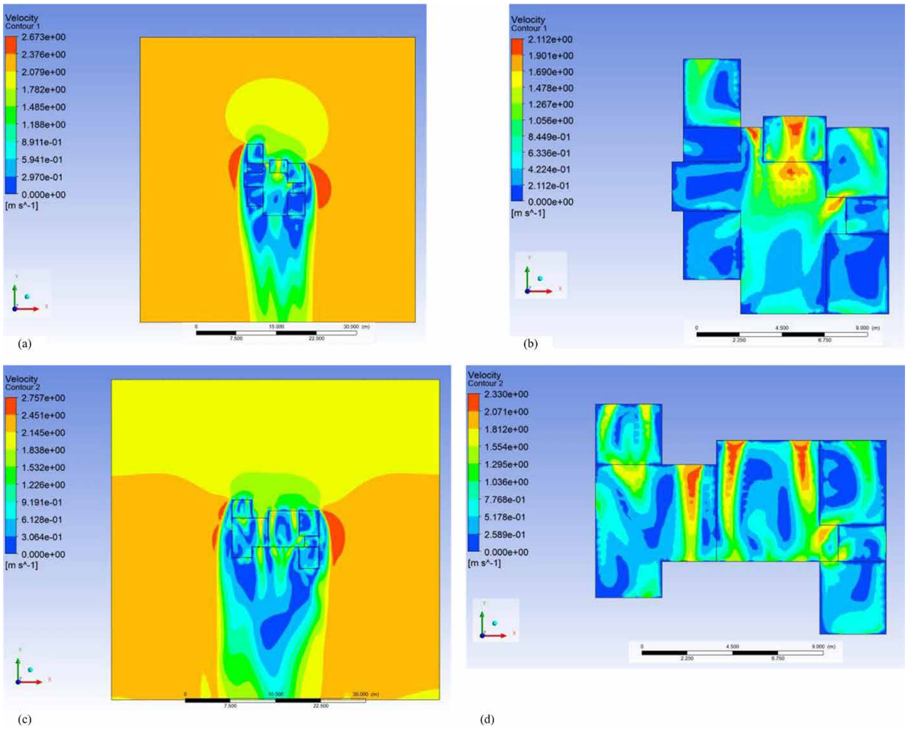

FIG. 12.9 Wind velocity distribution (height of 1.5m) of the optimised house and the new house
(a) (b) wind velocity map of the optimised house ((a) involves the outdoor space); (c) (d) wind velocity map of the new house ((c) involves the outdoor space)

Figure 12.9 shows the wind velocity map at a height of 1.5 m. It can be seen that the average wind velocity through the new house is greater than through the original house. In the new house, the wind passes easier through the public spaces (living room, dining room and patio) than in the original house (living room). Comparing the wind velocity maps and the connectivity maps in the VGA analysis, the distribution of the connectivity and the wind velocity were found as similar trends. To prove that, the correlation of the two indicators was analysed through statistical method.

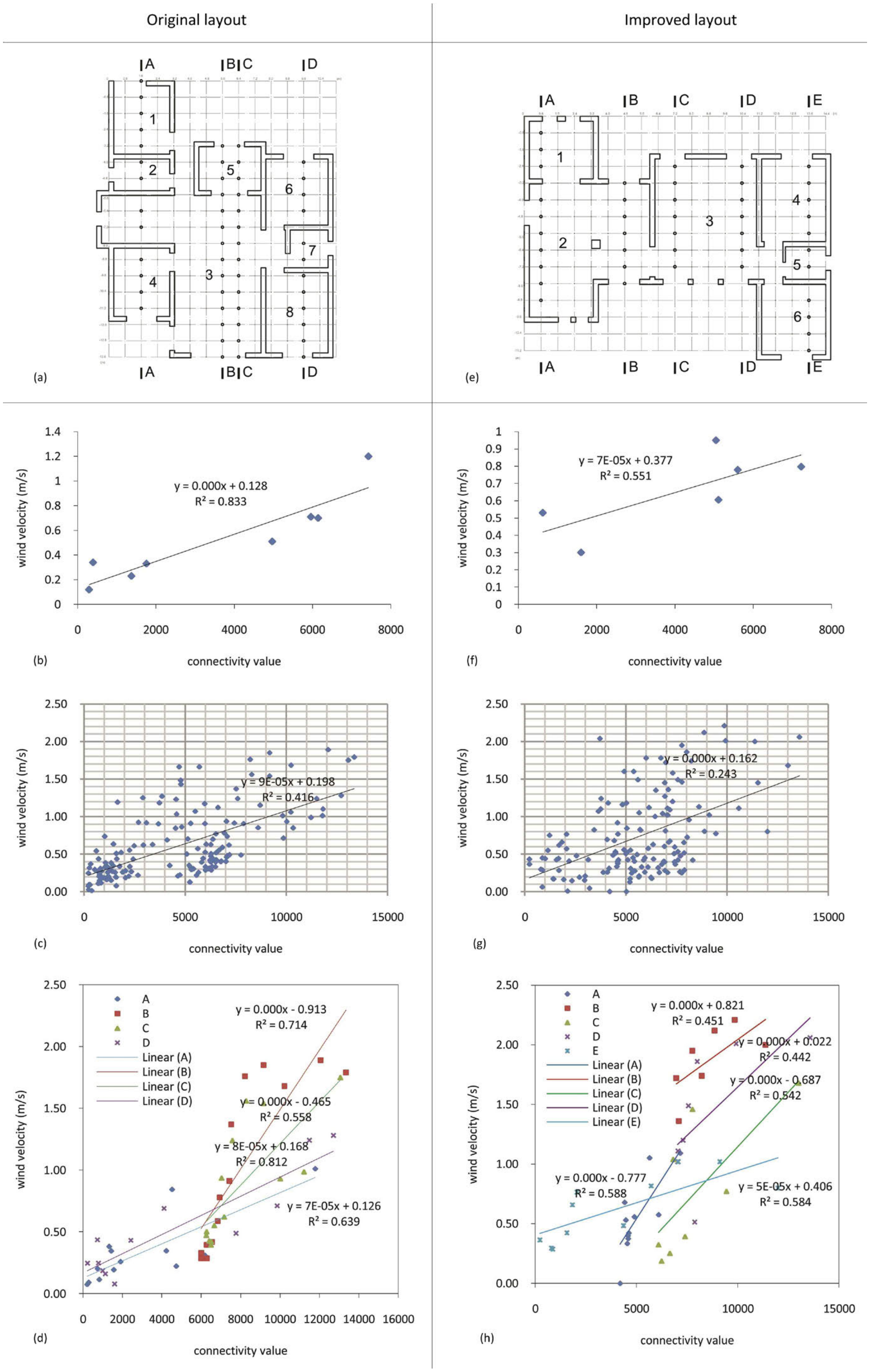

FIG. 12.10 Correlation analysis between the connectivity and the wind velocity

Because the grid setting is different in the CFD simulation and the VGA analysis, and due to the huge number of grids in the CFD simulation (around 8 million), part of the data was selected for the correlation analysis. Figure 12.10 (a) and (e) show the selected data of the two layouts. First is the average data of the rooms. There are 8 rooms in the original layout and 6 rooms in the improved layout. The linear correlation between the average connectivity and wind velocity is shown in figure 12.10 (b)(f). The coefficients of determination$R^2$are 0.83 and 0.55. The linear correlation is significant. Second are the selected points of all the rooms. The rooms were divided by a 800x800mm grid. The data (connectivity and wind velocity) near the grid points were chosen for the correlation analysis.
The linear correlation between the connectivity and wind velocity are shown in figure 12.10 (c)(g). The coefficients of determination$R^2$are 0.42 and 0.24. The correlation between the two factors is significant but the linear relationship is low. Third is the key point data on section A, B, C and D in the original layout and section A, B, C, D and E in the improved layout. The linear correlation between the connectivity and wind velocity is shown in figure 12.10 (d)(h). The coefficients of determination$R^2$are 0.44 and 0.91. The linear relationship between the two factors in the key points is significant.

The data analysis above revealed the positive correlation between the connectivity value and the wind velocity. The assumption that the spatial indicator and the airflow indicator are associated, which was found in chapter 9, is proved again in this case. That means the spatial indicator can reflect the trends of some features of airflow in the cross-ventilation. The spaces that have the highest potential to obtain cross-ventilation can be identified through the spatial analysis methods. Even the spatial indicator cannot reflect the real value of the airflow features, it is still valuable for the analysis of the spatial configuration in the early design stage. The advantages were described in chapter 9. For example, in this case, the connectivity value can be calculated in several minutes, however the CFD simulation took several hours for one model. Considering the time to build the model and to adjust the input parameters, much more time is needed for the CFD simulation.

12.6 Final design

This study focuses on the layout design of the new house. The layout of the ground floor of the new house was proposed by the author which was evolved from the optimized layout design proposed by the local government. However, in order to show the design of the new house completely, the general architectural design contents in the early design stage are briefly described in the following sections. Other issues related to sustainable design strategies for energy efficiency and thermal comfort are not discussed in this chapter.

12.6.1 General layout of the house on the site

Figure 12.11 shows the general layout of the house on the site. The house is in front of the small hill and faces the lake. The width is 14.6 meters and the depth is 11.6 meters. A front courtyard was set in front of the house and a back courtyard was set between the house the small hill. The major entrance is set at the west of the front courtyard.

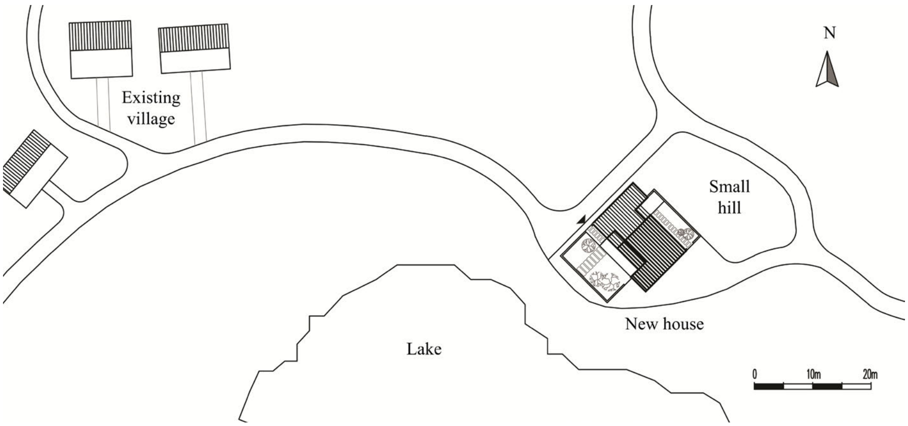

FIG. 12.11 General layout of the house on the site

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12.6.2 Floor plans

Figure 12.12 shows the final layout design of the new house and the functional distribution. Because the occupants need four bedrooms and plan to arrange two bedrooms on the ground floor and two bedrooms on the first floor, one bedroom of the original layout was deleted. Because the occupants do not want storage rooms, the storage rooms were deleted as well. To enhance the spatial diversity and satisfy the occupants' requests, the dining room was separated from the living room to the left. To make the living room obtain natural cross-ventilation directly, the kitchen was moved to the left, to close off the dining room. Therefore, the living room can open windows or doors on two sides to obtain cross-ventilation. In order to enhance the spatial diversity and to increase the public space, a patio was set between the living room and dining room. In order to enhance the diversity of the house, two verandas and courtyards were set in the front and back of the layout. The final spatial structure of the ground floor is shown in figure 12.12(a). The living room is in the middle of the layout. On the left of the living room, there are kitchen, dining room and stair. Right of the living room there are two bedrooms and a bathroom. The entrance and lobby are between the living room and the dining room. There is a patio located between the dining room and the living room and the patio faces the lobby. One large courtyard was designed in front of the building and one small courtyard behind the building. Accordingly, there are two verandas in front of and behind of the building.

Based on the shape of the ground floor, the layout of the first floor was proposed as well (figure 12.12(c)). On the first floor, there are two bedrooms and a bathroom as private spaces. A family room was set close to the patio. A special alterable room was designed in the middle of the layout. The changeable separations of this room can be opened and closed. Normally, the separations are opened. This space is a public space. If there are more residents, this room can be closed as bedroom. This design fits the occupants' demands. There is a corridor connecting the rooms. It was designed wider so that some activities can be performed in this corridor. A big terrace was designed in front of the corridor and a small balcony was designed behind the alterable room.

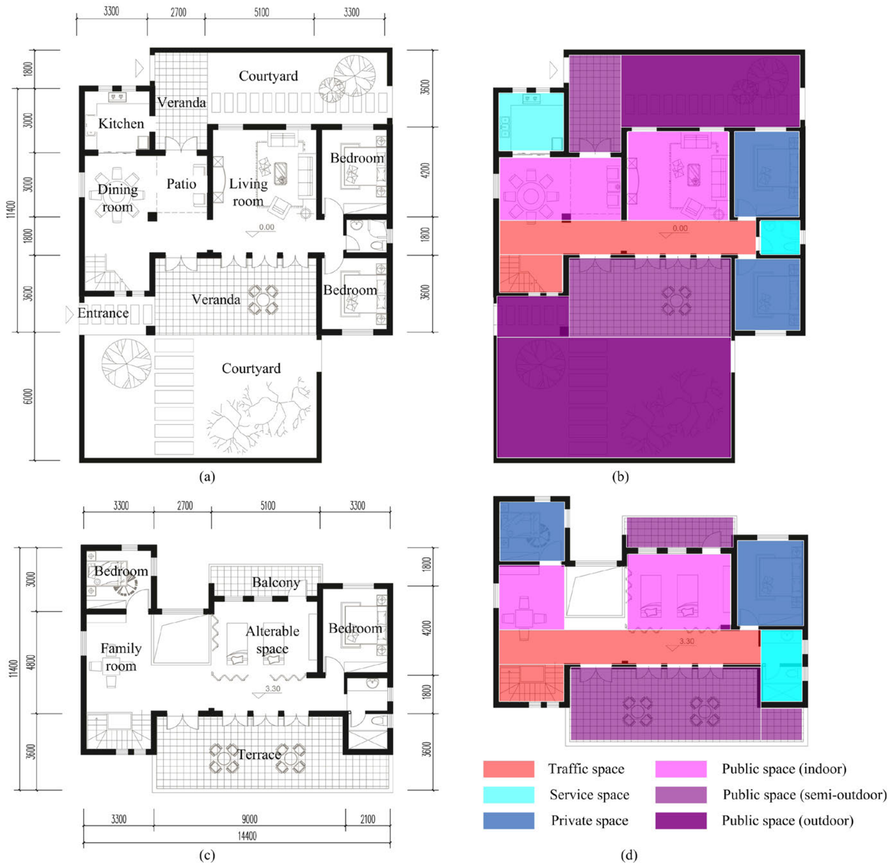

FIG. 12.12 The layout of the new house and the functional distribution.
(a) ground floor;(b) functional distribution of the ground floor;(c) first floor; (d) functional distribution of the first floor

Table 12.2 shows the comparison of the basic information of the new house and the original house. It can be found that the building area of the ground floor, the first floor and the total area are almost the same. However, the new house has more diverse spaces and more public area for the occupants' activities.

TABLE 12.2 Comparison of the basic information of the new house and the original house

	Plot area (m^2)	Area of build-ing (m^2)	Area of court-yard (m^2)	Total Area (m^2)	Area of ground floor (m^2)	Area of first floor (m^2)	Width (m)	Depth (m)	occu-pants	Type
type10	150	128	22	228	128	100	11.4(3)	13.4	5-6	Well-off
New house	232	128	104	227	128	99	14.6(4)	11.6	4-6	Well-off

	Living room +dining room	Dining room	Bed-room	Family room	Terrace	Balcony	Veranda	Patio	Court-yard
type10	1+1	0	6	0	1	2	2	0	1
New house	1	1	4+(1)	1	1	1	2	1	2

12.6.3 Façade design

The main focus of the façade design is the opening in the facades. The natural ventilation performance is defined by two aspects: the spatial configuration and the boundary conditions of the spaces connecting to the outdoor environment. Obviously, a larger opening means a greater ventilation potential. However, the opening area cannot unlimitedly increase because a larger opening area means more solar radiation, which is not preferred for thermal summer comfort. In the area studied, the size of the opening area in the façade is identified as window-to-wall ratio. The maximum window-to-wall ratio is identified in "The design standards on residential building energy saving 65%" (DJB 50-071-2016) (table 12.3). In this case, in the living room, which is the most important public space, the opening area was designed as large as possible to enhance more natural ventilation. But the window-to-wall ratio is still controlled under the limited value of the design standard. The maximum window-to-wall ratio is 0.56, which is smaller than the limit value of 0.60. For other rooms, the window-to-wall ratio is between 0.18 and 0.25, which is under the limit value of the standard. The windows can be opened completely. This is similar to the traditional windows of Chinese vernacular buildings. Figure 12.13 shows the elevations of the house.

TABLE 12.3 The limit value of widow-to-wall ratio on different building orientations

Orientation	Limit value of window to wall ratio
NW 60° -NE 60°	≤0.40
NE 60°-SE 30°, NW60°-SW 30°	≤0.35
SE30°-SW 30°	≤0.45
One room of one house (any orientations)	≤0.60

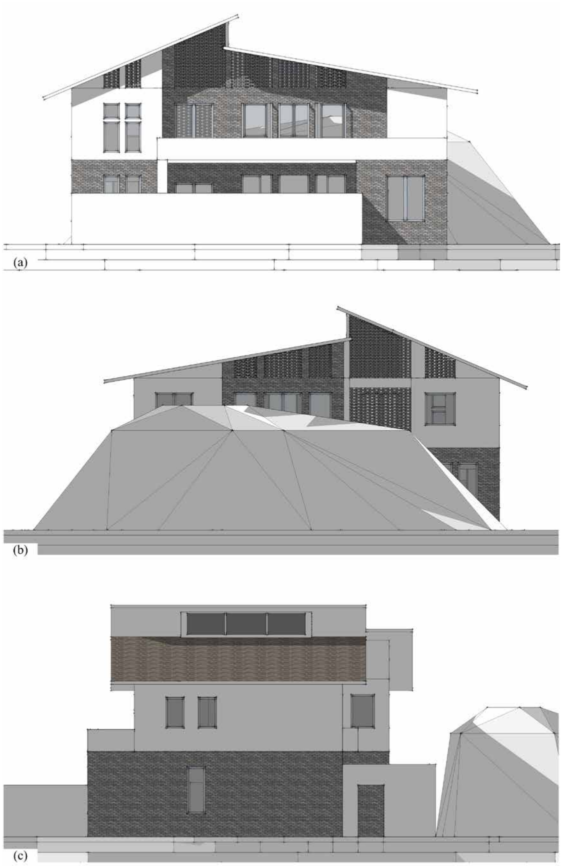

FIG. 12.13 The elevations of the house
(a) south-west elevation; (b) north-east elevation; (c) south east elevation

12.6.4 Appearance and structural design

The appearance combines the traditional and modern house design in the studied area (figure 12.14). The roof is designed as a double roof. One is a flat floor and another is a pitched floor. Between the two layers of the floor, the air can pass through. The idea is that the cross-ventilation can take away the heat during summer daytime.

Brick and a partly reinforced concrete structure are used for the house. This kind of structure is very common in this area. Therefore, local bricks are used. It is relatively cheap for the house owner. One layer of the roof is concrete and another is local black tiles.
There is no insulation on the wall and roof. There are three reasons for that. Firstly, insulation is not commonly used in the rural area because most of the rural houses are built by the farmers themselves; there is no design procedure, even if there are design standards for energy saving in rural residential buildings. Secondly, the rural house owner wanted to reduce the budget. Thirdly, if they do not use air conditioning, insulation is not useful for cooling.

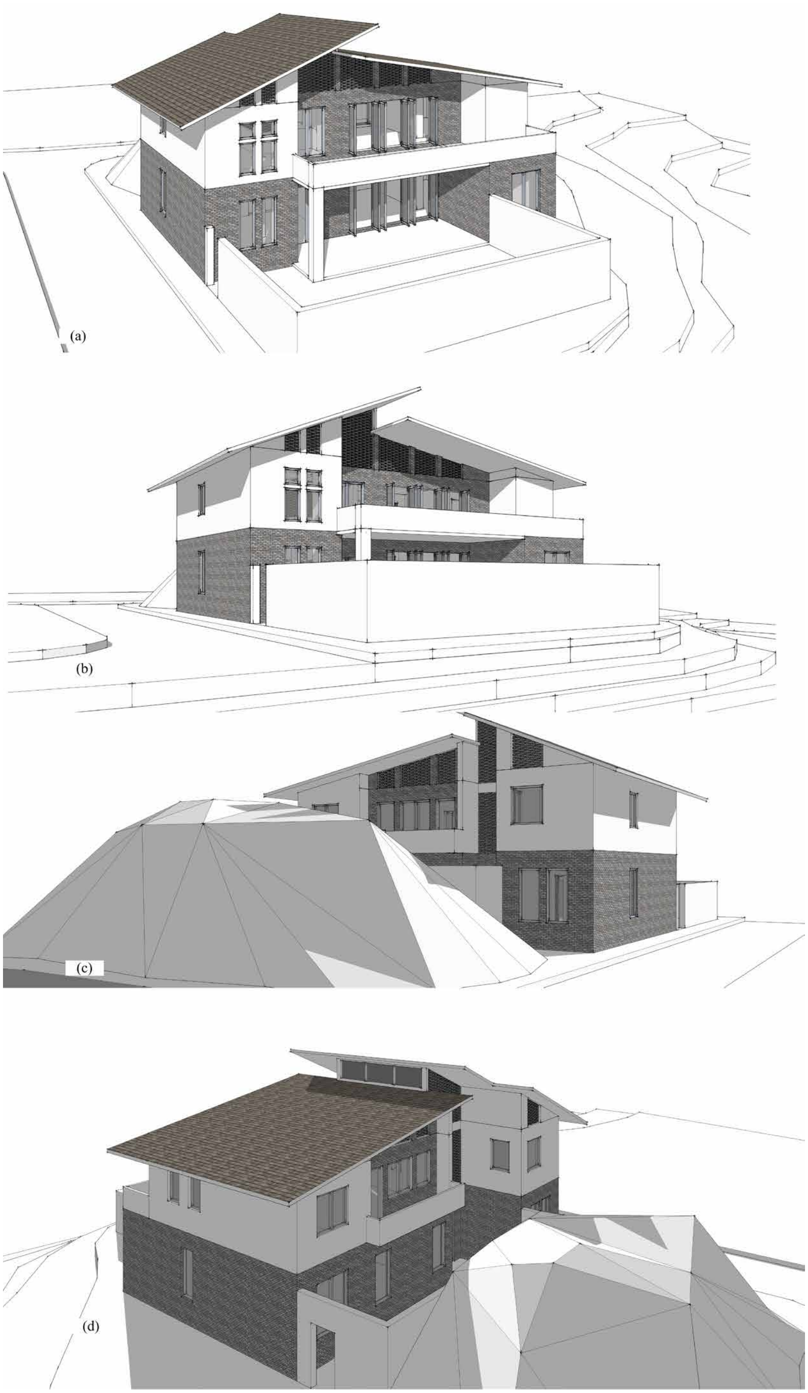

FIG. 12.14 The sketches of the new house

12.7 Conclusion

In this chapter, the optimised layout for a house proposed by the local government was analysed through the space syntax method and it was improved in a new house design. The results of the spatial analysis related to natural ventilation potential were validated through CFD simulation.

The goal of the improvements was to provide more diverse spaces for the occupants to choose from, to enhance cross-ventilation and to establish a favourable building microclimate. The improved house design provides more public spaces for the occupants, both on the ground floor and the first floor. This enhanced the diversity of the living spaces. As a conclusion from chapter 4, the local occupants would like to stay in the more open spaces during summer; the improved house gives this opportunity for the occupants. Through spatial analysis, it can be concluded that the accessibility and openness of the improved house and the major public rooms is better than the houses proposed by the local government (the ground floor). According to the conclusion in chapter 7, the high accessibility and openness mean the high potential to achieve cross natural ventilation. The occupants' behaviour model can be matched with the air movement behaviour. This means the spaces which the occupants prefer to stay are the spaces which have the high potential to obtain natural ventilation.

The studied case is still under construction. Future research will continue to field measurement to evaluate the building microclimate and thermal comfort of the house.