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# Landscape design method for a green community based on green building design theory*

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**Abstract:** Landscape design for a green community should be favorable for the ambient ecological environment and for enhancement of both the local climate of a residential area and the environmental quality of life. This paper presents optimization methods for plant landscape design that take account of results of comparisons of noise reduction effects, heat island temperature decreases and effects on ventilation. These methods are based on different plant configurations and various luminous environments, such as exterior sunshine and shaded areas after the simulation of exterior luminous, acoustic and thermal environments of a residential area using the analytic software ECOTECT, CADNA/A, and PHEONICS. Three different types of residential buildings are simulated including a faculty apartment in the Xixi Campus of Zhejiang University, the Huaqing Villa and the Gangwan Jiayuan faculty apartment of Zhejiang University, China, based on green building design theory. In addition, the methods and process flow of landscape design of green residential areas are also described for the improvement of the exterior physical living environment.

**Key words:** Landscape design, Green community, Green building, Exterior physical environment
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## 1 Introduction

Analysis of data from climate monitoring over the past 100 years shows that human activities are largely responsible for climate change. Before the industrial revolution, the atmospheric concentration of $CO_2$ was $280.0\times10^{-6}$, while by 2007 it had risen to $383.1\times10^{-6}$. The average global temperature has increased by 0.74 °C over the same period (Wang *et al*., 2010). Fifty percent of global energy is consumed in building construction and operation of which 34% is associated with construction (Wu and Yuan, 2010). The environmentally harmful practices of human-centrism need to be restrained to create a more natural ecological environment. From the 1970s, western countries set about restraining energy consumption (Xue, 2010). After 40 years of practice with building comfort improving, in developed countries, new building energy consumption per unit area has been reduced to 1/3–1/5 of that 30 years ago (Qiu, 2008).

High energy consuming buildings account for 98% of more than $4\times10^{10}$ m$^2$ of urban buildings in China (Wang, 2010b). In 2009, the Chinese Government promulgated a new policy on the positive resolution of climate change that vigorously advocated the development of green buildings (Wang, 2010a).

In view of the relatively inadequate resources per capita and weak foundations of the ecological environment, the promotion and implementation of the conception of sustainable development are of great urgency in China. The building industry, which consumes a great deal of energy and resources, must

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play a critical part in sustainable urbanization. The ecological design of residential buildings is a significant component of sustainable development and landscape design should also have an ecological focus. The planning and decision-making in the development of modern landscape planning theory needs to incorporate the relationships between people and the environment and between different land uses at a high level (Ding, 2008).

The possible contributions of urban and peri-urban green space systems, or green infrastructure, to both the ecosystem and human health have been critically reviewed by Tzoulas *et al*. (2007). It is increasingly recognized that more sustainable approaches are needed for planning and managing landscapes worldwide (Botequilha Leitao and Ahern, 2002). New tools are needed to apply sustainable principles effectively to planning and management. A simple decision-making model represents a theoretical framework for a tool comprising two sets of ecological indicators (Termorshuizen *et al.*, 2007). One set indicates the awareness of designers to consider ecological principles of sustainable planning. The other set indicates their performance in applying those principles quantitatively in designing the ecosystem pattern. A noise questionnaire study by Gidlof-Gunnarsson and Ohrstrom (2007) showed that for people either with or without access to a quiet space, better availability of nearby green areas was important for their well-being and daily behavior. Such areas reduced long-term noise annoyances and the prevalence of stress-related psychosocial symptoms, and increased the use of outdoor space. In high-density environments, on-site variables have a substantial impact on the influence of vegetation in lowering outdoor temperature. However, off-site variables such as high urban density and anthropogenic heat can negate the effects of sky view factors and altitude. Increasing tree cover from 25% to 40% can reduce daytime urban heat island intensity (UHI) by 0.5 °C (Giridharana *et al*., 2008).

Few publications address landscape design methods from the point of view of green buildings. This paper presents optimization methods for plant landscape design from a green building perspective based on results of comparisons of noise reduction effects, heat island temperature decreases and effects on ventilation.

## 2 Greening design

Ecological environmental design is concerned mainly with the amount of greening, the green ecological quality and the biological symbiosis of construction (Lin, 2007).

### 2.1 Amount of greening

The Green Building Evaluation Standards (GB/T 50378-2006) in China require a greening rate of residential area of not less than 30% and the public greening area per capita of not less than 1 $m^2$. To balance levels of carbon and oxygen, per capita residential green space should be no less than 9.64 $m^2$ (Wang *et al*., 2007). Specific greening areas for buildings are required and will play a crucial role in air purification, local climate regulation, noise reduction, health care, energy saving, etc. (Huang and Wang, 1998).

### 2.2 Green ecological quality

The Green Building Evaluation Standards (GB/T 50378-2006) require cultivating the appropriate indigenous plants for local climate and soil conditions which are of low maintenance, weatherproof, pest resistant and do no harm for human body and cultivating multiple types of plants to form multi-level plant communities comprised of trees, bushes and grasses according to local climate and natural distribution of plants and there should be at least three trees in every 100 $m^2$ of green land. The detailed rules for Green Building Evaluation Technology (Architectural Science 205, 2007) specify that the plant configuration should show local characteristics, the abundance of local plant resources and plant landscapes with distinguishing features. Multi-level greening through combinations of trees, bushes and grasses should be adopted to form a greening system with rich levels and favorable ecological benefits. Fig. 1 shows a cross-sectional view of ecological plant communities representing an ecological structural system of multi-level greening comprised of trees, bushes, and grasses.

### 2.3 Organic symbiosis of buildings

The following configuration principles should be taken into account in landscape design:

1. Select plants suited to local conditions: plant

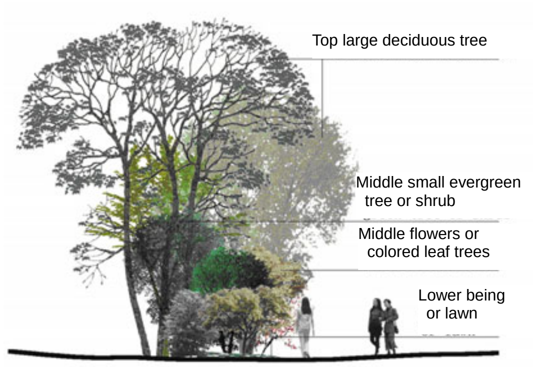


**Fig. 1 Cross-sectional view of ecological plant communities**

local seeds as much as possible to improve survival rate and facilitate maintenance and future management.

2. Functional priority: high trees should be planted at an adequate distance from buildings and preferably not on the south side of buildings because of daylight and ventilation constraints.

3. Harmony and unification: various plants and corresponding configurations should be adopted to create artistic landscapes according to different characteristics of every space. Residential communities need uniform types of plants to form the greening style of a whole region. Human culture, history, and environment should all be taken into account for harmony.

## 3 Luminous environment of residential areas

It is necessary to achieve harmony between the ecological environment and living conditions in landscape design. A reasonable configuration of plants is required based on the heliophilicity of plants for a healthy development in accordance with different sunshine and shading conditions in various residential areas undergoing planning and construction. This approach should influence the utilization of the buildings and environment.

The faculty apartment in the Xixi Campus of Zhejiang University, Hangzhou, China was taken as an example in this case. The luminous environment of the residential area and its effect on landscape design have been analyzed using simulation with the ecological design software Autodesk Ecotect Analysis by the SquareOne Company.

### 3.1 Project introduction

Located in the Xixi Campus of Zhejiang University, the faculty apartment covers an area of 34155 $m^2$ in a construction area of about 90888 $m^2$. There are a total of 10 high-rise residential buildings, each of which is about 30 m high, and two underground garages.

### 3.2 Simulation of the luminous environment of the residential community

Hangzhou City is located on the eastern coast of China in a subtropical monsoon zone. Daily sunshine averages 5.4 h and reaches a maximum in summer. The minimum difference in average daily sunshine between summer and winter is 3.6 h. The city is designated a Type IV climatic zone among the five luminous climate zones nationwide, and the stipulated outdoor critical illumination is 4500 lx.

Fig. 2 shows the average daily radiation which is accumulated on the site through the simulation under outdoor illumination of 4500 lx in early spring. Illumination of 3500–4500 lx was adopted in the simulation and is shown on a scale from dark to light with scale divisions of 100 lx. The all-day accumulated shade is also shown. The exterior environment of the residential area is divided into four types: sunny areas, semi-sunny areas, semi-shady areas, and shady areas.

### 3.3 Use of luminous environment analysis for guiding plant cultivation

Different types of plants with varied heliophilicities should be cultivated in areas with various luminous environments. Suitable plants are arranged in conformable areas based on plant characteristics (Table 1).

## 4 Acoustic environment of residential area

The acoustic environment of a residential area is closely associated with residential health and comfort. The Green Building Evaluation Standards state that residential environment noises should meet the requirements of the Acoustic Environment Quality Standards (GB 3096-2008) (Table 2).

Noise control in the exterior environment of a residential area relies mainly on plants. In addition to

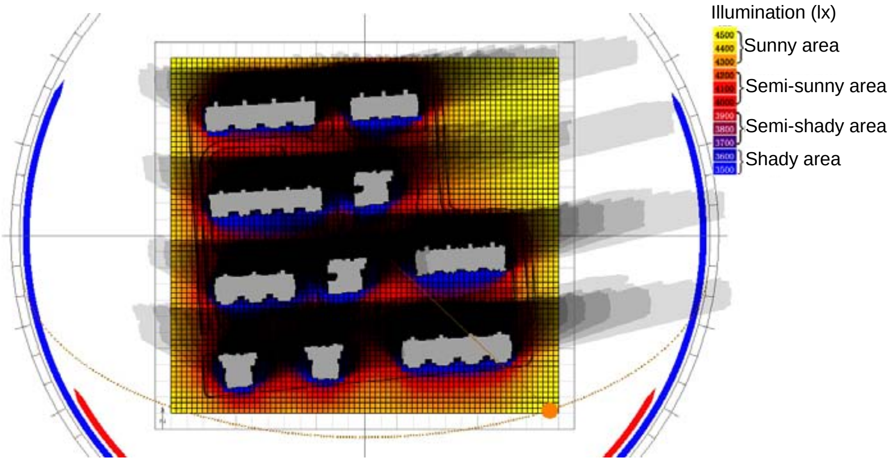


**Fig. 2 Simulation analytic diagram of luminous environment of residential area**

**Table 1 Plant configuration in areas of different luminous environments**

| | Suitable plants* | Plants actually cultivated |
|---|---|---|
| Sunny areas | Poplar, willow, elm, locust tree, cypress, camphorwood, zelkova, forsythia, Chinese rose | Camphorwood, zelkova, Chinese rose |
| Semi-sunny areas | Oriental cherry, peach, magnolia, maple, plum | Magnolia denudate, oriental cherry, red maple, peach |
| Semi-shady areas | Chinese fir, ivy, camellia, azalea, | Ivy |
| Shady areas | Plantain lily, begonia, holly, fern | Plantain lily |

* Guangzhou Cuiting Horticulture Co., Ltd. (2009)

**Table 2 Equivalent sound level limits of various acoustic environment function areas (dB)**

| Environment function area | Sound level limit | |
|---|---|---|
| | Day | Night |
| Villa, sanitarium | 50 | 40 |
| Residence, culture and education | 55 | 45 |
| Commerce, downtown | 60 | 50 |
| Industrial area | 65 | 55 |
| Trunk line, railway | 70 | 55 |

the absorption of part of the acoustic energy by leaves in resonance with sound waves, the gaps between leaves and branches can also absorb part of the acoustic energy by acting like a porous sound absorbing material. Street greening enhances the total acoustic energy absorption of the environment and lowers the noise level of the block. The noise reduction function of trees is closely related to the leaf density, forest belt structure and green belt distribution (Guo, 2005). The ability of combinations of trees, shrubs and grass to block and absorb noise is significantly higher than that achieved by a single barrier (Zhou, 1998).

The noise control design of the landscape zone of Huaqing Villa was taken as an example in this case and the computer simulation software CADNA/A was adopted in the analysis of the noise reduction function of green belts in the community.

### 4.1 Project introduction

Huaqing Villa is located in Dingjia Village at the southern foot of Mount Linping, Hangzhou, China. The road system determines the layout of the community which is divided into two blocks by Anping Road. The southern block is adjacent to Baozhang Road and Ouhuazhou Street. Since these two main roads go through the community, a noise reduction forest is planted to offset the possible effect of vehicles on noise in the surrounding residential buildings.

The residential area including residence, culture and education buildings (Table 2) is a quiet area. The acoustic environment of the area along Ouhuazhou Street and Baozhang Road is classified as trunk line and railway and is affected by main traffic lines. Therefore, special sound insulation structures need to be included on the side facing the road. The parameters set for simulation of all the road sections are shown in Table 3.

**Table 3 Parameters for simulation of all road sections**

| Road section | Daily total traffic flow (set) | Maximum speed per hour of car (km/h) | Maximum speed per hour of truck (km/h) | Road surface material | Road width |
|---|---|---|---|---|---|
| Ouhuazhou Street | 25000 | 80 | 60 | Tar asphalt | Two-way four lanes |
| Baozhang Road | 20000 | 70 | 50 | Tar asphalt | Two-way four lanes |
| Main traffic line in the community | 3000 | 40 | – | Tar asphalt | Two-way two lanes |
| Secondary traffic line in the community | 1000 | 30 | – | Tar asphalt | Two-way two lanes |

### 4.2 Simulation of the acoustic environment of the community

The CADNA/A environmental noise simulation software was adopted for the simulation and the modeling was based on a planning and design diagram. Some parts of buildings were simplified in the model. The calculation was performed according to a grid of 5 m×5 m squares and the acoustic source receiving point was at a height of 2 m.

#### 4.2.1 General analysis of the current noise condition of the community

The noise distribution of the community during the day and night is shown in Fig. 3 in which the dark and light colors represent different noise levels. The results of simulation indicate that the general acoustic environment of the community is good as the noise level is around 55 dB during the day and around 45 dB at night. However, there is a strong noise effect in several areas. The noise in the community comes mainly from internal roads and the buildings with noise levels beyond the required limits caused by noise from the surrounding roads are concentrated mainly on one side of Baozhang Road and both sides of Anping Road. Therefore, there is a lot of noise between these buildings.

#### 4.2.2 Analysis of noise surrounding the community

Simulations of the noise distribution on Baozhang Road and Anping Road surrounding the community during day and night are shown in Figs. 4 and 5. The variation in color from light to dark indicates increasing noise levels. The results of simulations indicate that the noise levels on Baozhang Road and Anping Road are around 70 dB during the day and around 63 dB at night, and both exceed the limits. Noise in the community comes mostly from these two external roads and the noise control for the two areas should be emphasized in planning and design.

#### 4.2.3 Analysis of the internal noise of the community

A simulation of noise distribution on both sides of internal roads in the community during day and night is shown in Fig. 6. The variation in color from light to dark indicates increasing noise. The results of the simulation indicate that the internal roads of the community affect the noise levels in residential buildings. The noise level on the roadsides of the residential area is around 65 dB during the day and around 58 dB at night, and both are out of limits.

### 4.3 Use of acoustic environment analysis for guiding plant cultivation

The standard protection forest design of Huaqing Villa is shown in Fig. 7. The influence of road noise within the community has been taken into account completely. Evergreen trees of Zhejiang camphorwood or southern magnolia are planted on the outermost layer of the enclosing wall and coral trees are planted on the secondary layer so as to reduce noise by 10–15 dB inside the community.

The plant design of the Huaqing Villa Community is shown in Fig. 8. The upper layer is composed mainly of evergreen trees (*Pinus elliottii* and *Pinus thunbergii*) and the lower layer is composed of flowers and bushes to achieve a noise reduction of 5–7 dB for low-rise buildings (Liu, 2007).

## 5 Thermal environment of residential areas

The comfort of the exterior thermal environment of residential areas is also significant and associated with the residents’ health. Relevant regulations can be found in the Green Building Evaluation Standards (GB/T 50378-2006).

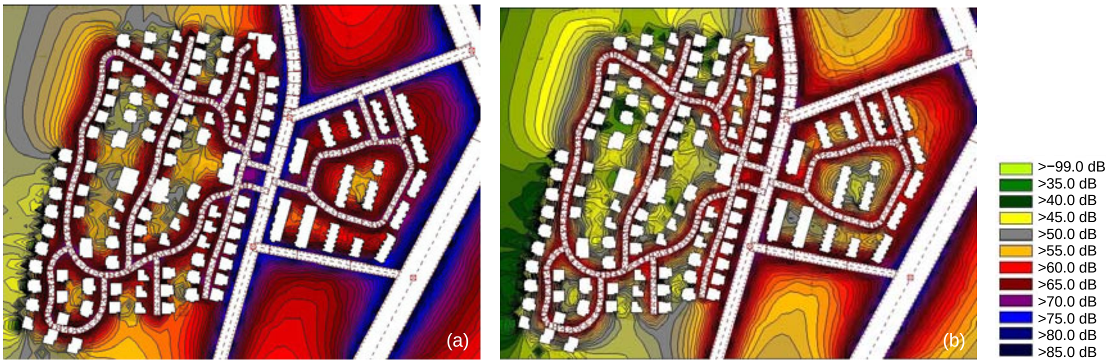


**Fig. 3  Noise distribution diagram of community during day (a) and night (b)**

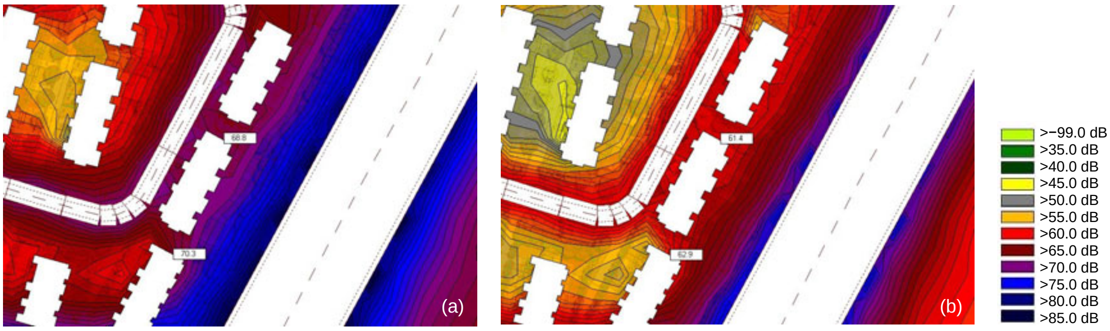


**Fig. 4  Noise distribution diagram on both sides of Baozhang Road during day (a) and night (b)**

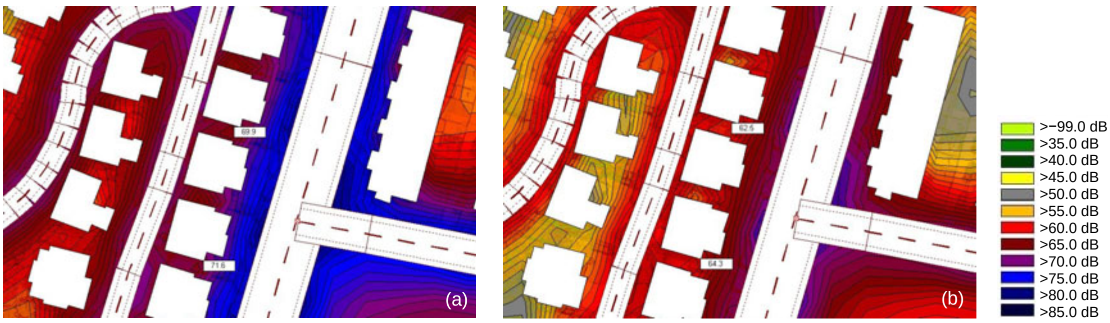


**Fig. 5  Noise distribution diagram on both sides of Anping Road during day (a) and night (b)**

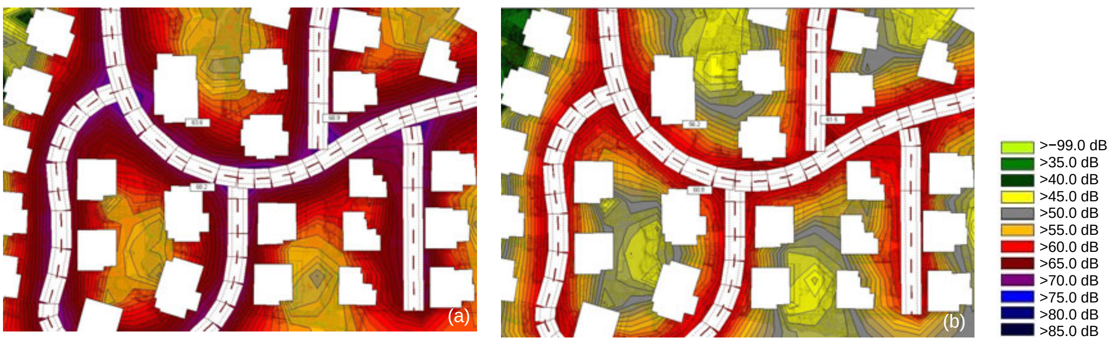


**Fig. 6  Noise distribution diagram on both sides of internal roads of community during day (a) and night (b)**

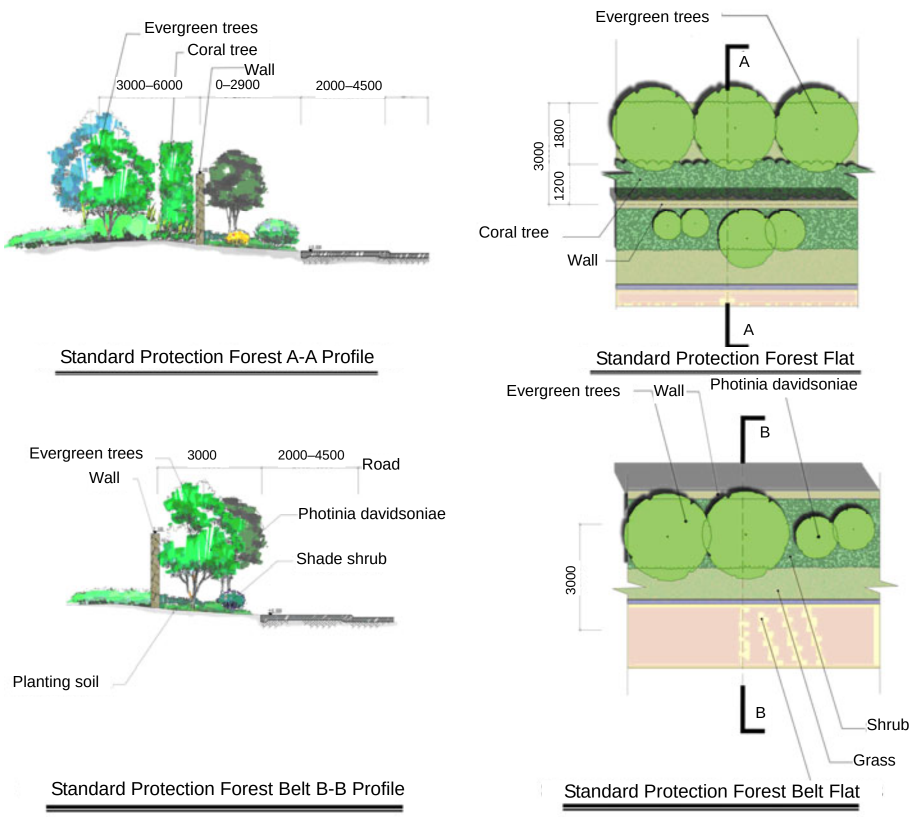


**Fig. 7 Standard protection forest design of Huaqing Villa, Hangzhou, China**

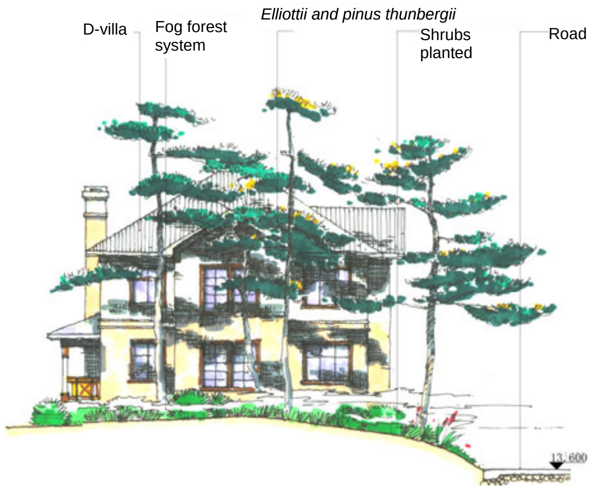


**Fig. 8 Sectional view of Huaqing Villa landscape design**

1. Average daily heat island intensity of exterior environment of residential area should not be higher than 1.5 °C.

2. Wind environment of residential area contributes to walking comfort outdoor in winter and natural ventilation in transient season and in summer.

The Gangwan Jiayuan faculty apartment of Zhejiang University, Hangzhou, China is taken as an example in this case. Analysis of the effect of greening on ventilation and temperature reduction was performed through simulation with the Flair Module of PHEONICS, a computer software from the British CHAM Company, and the standard Kmodl model was adopted.

## 5.1 Project introduction

Located in the northern Zijingang Campus of Zhejiang University, the Gangwan Jiayuan faculty apartment of Zhejiang University has Liuxiang Road to the north, Zijingang Road to the west and the students' dormitory to the south. The site covers a total area of 125000 m$^2$. There are a total of 23 high-rise residential buildings, each of which is about 30 m high.

## 5.2 Simulation analysis of the wind environment of the community

As it is stated in the national Green Building

Evaluation Standards (GB/T 50378-2006) that the pedestrian wind speed should be lower than 5 m/s surrounding buildings so that it will not influence the comfort of outdoor activities and building ventilation, the standard for wind environment comfort was as follows: average wind speed <5 m/s at 1.5 m high.

The prevailing wind directions in Hangzhou are characteristic of the monsoon climate. The prevailing wind directions in the urban area are north-northwest (NNW) in winter and south-southwest (SSW) in summer. The effects of wind speeds in those directions in summer and winter on the wind environment of the community were simulated: NNW: average 2.6 m/s; SSW: average 2.7 m/s.

The wind speed distribution of the frequent northwest winds of 2.6 m/s through the community in winter is shown in Fig. 9. The wind speed inside the community is generally lower than 5 m/s. However, the wind speed in some parts exceeds 5 m/s. The wind environment of the frequent southwest winds of 2.7 m/s through the community in summer is shown in Fig. 10. The wind speeds of all the positions in the community are below 5 m/s.

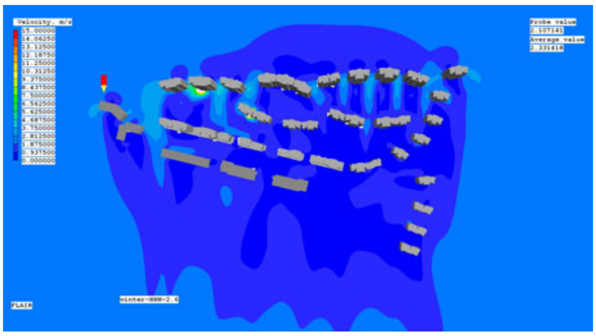

**Fig. 9 Wind speed distribution diagram of NNW wind of 2.6 m/s through community in winter**

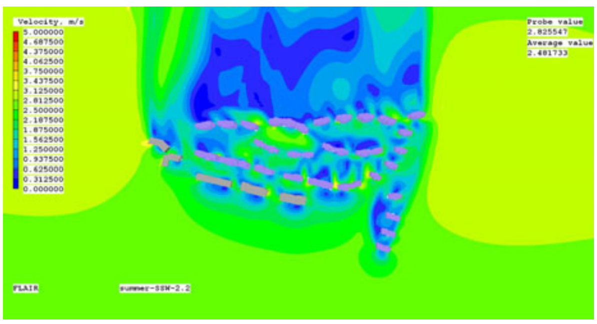

**Fig. 10 Wind speed distribution diagram of SSW wind of 2.7 m/s through community in summer**

### 5.3 Wind environment improvement measures

The results of simulation indicate that the wind environment in most of the pedestrian areas meets the requirements. But the wind speed in some parts exceeds 5 m/s. The gap between two buildings on the northern side of the community forms a through-draught which will cause gusts with high wind speed. The wind speed in some locations on the northwestern side is even higher than 10 m/s. Although some landscape plants are arranged between the two buildings in this case, they have undesirable wind resistance and pedestrians often feel uncomfortable when walking between the buildings. Therefore, the wind resistance of plants should be emphasized in the landscape design in future to enhance the wind environment. Evergreen plants with favorable wind resistance can be arranged between the buildings on the northern side of the community to block wind and reduce the high wind speed in pedestrian areas.

### 5.4 Analysis of the heat island effect of the community

The detailed rules for Green Building Evaluation Technology (Architectural Science 205, 2007) requires that the average daily outdoor heat island intensity should not be higher than 1.5 °C in residential areas.

The results of wind simulation indicate that the outdoor wind speed of the community in summer is not lower than 0.2 m/s and meets the requirement of a heat island intensity of lower than 1.5 °C.

The greening configuration of Gangwan Jiayuan faculty apartment is shown in Fig. 11. The temperature in the forest usually is 3–5 °C lower than in open space in summer, and 2–4 °C higher in winter (He,


**Fig. 11 Greening configuration diagram of Gangwan Jiayuan of 2.7 m/s through community in summer**

2003). In this case, the plants with strong temperature reduction function are arranged in the central area of the group of buildings that has a severe heat island effect, and a green isolation belt is established in the surrounding area.

## 6 Discussion

A series of recommendations and measures with respect to landscape design have been summarized through the case analysis in this study and need to be emphasized and accomplished at every step in the design process.

### 6.1 Plant diversity configuration

Plant diversity is beneficial to ecological circulation and balance. It facilitates the improvement of space utilization in green land and provides a desirable living environment for creatures. It is important to adopt the composite-layer greening of trees, bushes and grasses and arrange plant communities with a suitable structure. Plants with plenty of thick leaves with strong transpiration and carbon fixation abilities should be used. Big deciduous trees can be arranged for upper space on account of their shading and transpiration. Small evergreen trees can be arranged for the secondary space on account of their carbon fixation. Evergreen bushes can be arranged for lower space on account of their larger leaf area. Considering factors such as summer ventilation, a reasonable green space configuration should be 1 (tree/plant): 6 (shrubs/plants):20 (lawn/$m^2$):29 (green/$m^2$) (Chen *et al.*, 1998).

### 6.2 Distribution of plants based on the luminous environment

1. Exterior luminous environment zoning

The exterior luminous environment of residential areas can be divided into four types according to the simulation: sunny, semi-sunny, semi-shady and shady areas. Plants with different heliophilicities can be arranged in the four types of areas. In other words, the locations should be arranged based on the characteristics of the plants.

2. Building operating conditions

Actual service conditions of buildings should also be considered. Only small bushes should be planted near windows within a distance of 5 m to prevent any undesirable influence on sunshine and ventilation of residential buildings; big deciduous trees can be planted on both sides of the eastern and western gable walls for shading in summer and adequate sunshine with leaves fallen in winter (Tsinghua University, 2005).

3. Landscape conditions

Evergreen trees can be planted in areas with strong radiation indicated by analysis of the average daily radiation accumulated on the site. They can provide shade in every season. Recreational facilities such as pavilions are also needed. As for areas with less radiation, deciduous trees can be planted so as to provide shade in summer and adequate sunshine with leaves fallen in winter.

### 6.3 Contribution of plants to noise control

1. Plant selection

Dense plants with large and thick leaves arranged evenly, and low branches should be selected.

2. Arrangement method

Noise reduction is proportional to arrangement density. At any given density, a staggered pattern can achieve the best noise reduction effect. The second best are an aligned pattern or a scattered point pattern. However, when the arrangement density is very low, the noise reduction effect of the scattered point pattern is the best and the aligned pattern the worst.

3. Plant arrangement in key positions

The roads inside the community and the entrances to the community need to achieve reasonable noise reduction depending on plant utilization.

### 6.4 Improvement of the thermal environment by plants

1. Appropriate wind environment

Some evergreen trees with strong wind resistance should be arranged between buildings on the prevailing wind side in winter to block wind and reduce the wind speed in pedestrian areas.

2. Improvement of air quality by plant

In areas with poor air quality, air quality can be improved by increasing ventilation ways and intensities and by planting plants with air purification ability.

3. Improvement of heat island effect by plants

The heat island effect is severe in areas with poor ventilation in the center of groups of buildings. Therefore, plants with strong function and capable of temperature reduction should be used.

## 7 Conclusions

A series of design flows and operation methods are proposed to provide a comprehensive and scientific landscape design plan to achieve optimization of the exterior physical living environment of green residential areas. The plan is based on plant diversity configuration evaluation, luminous environment simulation for plant zoning, acoustic environment simulation for noise control, and thermal environment simulation, and will form a basis for climate improvement in the landscape design of green residential areas.

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