Research on planting arrangement of coconuts in Zhanjiang city under the climate adaptive design

Yiwei Chen and Chunhua Xia1

Department of Landscape Architecture, Guangdong Ocean University, Zhanjiang, Guangdong, 524088 China

1 Corresponding author email: 18927999881@163.com

Abstract. The essential factor that enables people to stay in the active space depends on whether the area can provide comfort to the human body. According to this theory, the climate-adaptive design will effectively improve space vitality. First of all, this paper analyzes and summarizes the climate in Zhanjiang City based on the “golden section method,” obtaining that the comfort of Zhanjiang is dominated by thermal discomfort, and trees can improve the city’s thermal comfort level through shading. Then we established the sun’s orbit map and the trajectory model of coconut shadow changes and used the penetration threshold theory, the following coconut planting arrangement is derived: (1) when the planting quantity is less than or equal to seven or more than 608, there is a reserved space, and the planting arrangement of coconuts is compact; (2) when the number of coconuts is more than seven and less than 608, there will be no reserved space. Currently, the planting arrangement of coconuts is random, and the area of planting space units is less than or equal to 71.6×m2 (x is the number of coconuts). These findings will help the designer offer better guidelines for planting and improving the vitality of the space.

1. Introduction

Climate adaptive design is a design technique that aims to make full use of climate resources in the design process—creating a healthy and comfortable environment. In outdoor space activities, people will choose the activity space according to the aesthetic cognition and activity experience. However, the essential factor that enables people to stay in the active space depends on whether the area can provide comfort to the human body [1-2]. Therefore, using a climate-adaptive outdoor space design can activate spatial vitality, guide pedestrian activity, and organize spaces more effectively.

Initially, climate adaptive design was used in architectural design [3]. With the development of landscape architecture and urban planning, adaptive climate design was gradually mentioned in urban planning and landscape architecture. In landscape architecture, the research direction of a climate-adaptive design can be divided into the following categories: (1) investigating the microclimate in the environment constructed by architecture, water bodies, and vegetation. Many factors affect the microclimate. For example, Qiang Zhan studies the impact of spatial environmental elements on the microclimate [4], Kaixuan Chen studies different landscape spaces Influence on microclimate [5], and Jingfan Wang studied the influence of different plant combinations on the microclimate [6]; (2) studying the effects of different plant species, canopies, and canopy structures on human comfort. Yuxia Duan studied the effect of canopy shading on human comfort [7]. There are many studies on the impact of plant species. Rahman MA [8] and Ling Kong [9] studied the effect of different tree species on comfort, while Renwu Wu studied the impact of varying bamboo types on comfort [10]; and (3)
constructing outdoor space comfort evaluation and prediction models [11-12]. In these studies, we learned that plants, as landscape architecture elements, can improve human comfort in outdoor space through planting design. In the existing studies, more attention is paid to plant types' effect on the comfort in the space, while few studies on arranging plants to enhance human comfort in an outdoor space. Although Qunshan Zhao proposed the effect of clustering, dispersing, and equal intervals arrangement of trees on human comfort through numerical simulations [13], Qunshan Zhao's research is the influence of a small number of plants in residential areas on human comfort. He focuses on studying plant arrangement on the overall cooling effect, which has limited guiding significance for improving outdoor space comfort. Further, none of the published research explores how to design plants arrangements effectively to maximize the vitality of the outdoor space while improving the comfort.

This paper explores a way to maximize the vitality of the outdoor space while improving human thermal comfort. This paper, through an analysis and summary of the regional climate, establishes the sun’s orbit map and the trajectory model of coconut shadow changes and uses the penetration threshold theory research the arrangement of coconut planting.

2. General comfort level in Zhanjiang City 2000–2017

2.1. Methods of meteorological data acquisition and analysis

Based on the Zhanjiang City Meteorological Station, No. 59658, we used the daily dataset of China’s ground climate and the integration statistics by the China Meteorological Data Network (http://data.cma.cn) to search and collect data for Zhanjiang between 2000–2017.

Zhiwei Zhang and Shigong Wang proposed a method for calculating human comfort based on the golden section method [14], using the following formula to adjust the optimal comfort temperature in Zhanjiang:

\[ T_{o} = 22.7 \times \left[ 1.0 - 0.3 \sin(\theta - 23.5) \right] - \left| 0.3 \times \cos(15 \times (M - 1)) \right| - 2.0 \times \tan \left( \frac{H}{100} \right) \]  

(1)

In the formula, \( T_{o} \) is the optimum comfortable temperature, \( \theta \) is the latitude, \( M \) is the month, and \( H \) is the altitude. \( [1.0 - 0.3 \sin(\theta - 23.5)] \) is the latitude correction term, \( |0.3 \times \cos(15 \times (M - 1))| \) is the seasonal effect term, and \( 2.0 \times \tan \left( \frac{H}{100} \right) \) is the altitude adjustment term. The latitude correction term will be used in areas other than the Tropic of Cancer, and the altitude adjustment item will be used when the local altitude is higher than 500 meters.

According to the meteorological elements, such as precipitation, relative humidity, average temperature, and wind speed, the constructed somatosensory temperature expression is as follows:

\[ T_{a} \leq T_{c} : T_{g} = T_{a} + A \exp \left[ 0.013 \left( T_{a} - T_{c} \right) \times (RH - RH_{s}) - 1 \right] - 0.01 \left( T_{a} - T_{c} \right) \times v \]  

(2)

\[ T_{a} < T_{s} : T_{g} = T_{a} - A \exp \left[ 0.013 \left( T_{s} - T_{a} \right) \times (RH - RH_{s}) - 1 \right] - 0.01 \left( T_{s} - T_{a} \right) \times v. \]  

(3)

Table 1. The classification standards of different comfort levels [14].

| Classification       | Degree | Feel       | Criteria for the classification |
|----------------------|--------|------------|---------------------------------|
| Hot Zone             | Level 4| Extremely hot | \( T_{g} > 31 - Dt_{a} \)      |
|                      | Level 3| Hot        | \( 28 - Dt_{a} < T_{g} \leq 31 - Dt_{a} \) |
|                      | Level 2| Relatively hot| \( 25 - Dt_{a} < T_{g} \leq 28 - Dt_{a} \) |
| General comfort Zone | Level 1| Slightly hot | \( 22.7 - Dt_{a} < T_{g} \leq 25 - Dt_{a} \) |
|                      | Level 0| Comfortable | \( 22.7 - Dt_{a} < T_{g} \leq 25 - Dt_{a} \) |
|                      | Level -1| Slightly cool | \( 13 - Dt_{a} < T_{g} \leq 18 - Dt_{a} \) |
| Cold Zone            | Level -2| Cool       | \( 8 - Dt_{a} < T_{g} \leq 13 - Dt_{a} \) |
|                      | Level -3| Slightly cold | \( 3 - Dt_{a} < T_{g} \leq 8 - Dt_{a} \) |
|                      | Level -4| Cold       | \( -5 - Dt_{a} < T_{g} \leq 3 - Dt_{a} \) |

\( a Dt = 22.7 - T_{s} \)
In the formula, the coefficient $A=36.75 \times (1-0.618) \approx 14$, $T_d$ is the body temperature ($^\circ C$), $T_a$ is the average temperature, $T_o$ is the optimum comfortable temperature, $v$ is the average wind speed (m/s), $R_H$ is the relative humidity, and $R_H_s$ is the optimum relative humidity. Moreover, $R_H_s=0.618$ when there is precipitation, and $R_H_s=0.5$ when there is no precipitation.

We calculated the daily value data of Zhanjiang City from 2000 to 2017, according to formulas (1), (2), and (3). Furthermore, Table 1 shows the classification standards of different comfort levels and statistics on the number of days of comfort classifications in Zhanjiang City from 2000 to 2017 [14].

2.2. Analysis result
Using the calculation of human comfort based on the “golden section method,” we obtained Zhanjiang City's comfort change and the overall trend between 2000–2017. According to the temperature, December, January, and February are divided into winter; March, April, and May are spring; June, July, and August are summer; and September, October, and November are autumn.

Among them, Figure 1 shows the overall change in the degree of daily comfort in Zhanjiang City from 2000 to 2017, and Figure 2 shows the changes in the number of days of the General Comfort Zone in the seasons in Zhanjiang City from 2000 to 2017. Accordingly, we can conclude that the overall feeling of human comfort is mainly cold discomfort in winter and hot discomfort in spring, summer, and autumn in Zhanjiang city between 2000 to 2017. Among the four seasons, the number of days in the General Comfort Zone gradually increases in spring, decreases slowly in winter and autumn, and remains unchanged in summer.
Figure 5. The changes situation in the number of the day of General Comfort Zone in Zhanjiang City from 2000 to 2017.

Figure 6. The changes in the number of the days feeling of cold under the broad classification in Zhanjiang City from 2000 to 2017.

Figure 3 shows the changes in the number of days that the three classifications about comfort in Zhanjiang City was in the Hot Zone from 2000 to 2017. Figure 4 shows the changes in the number of days that Zhanjiang City from 2000 to 2017. Furthermore, Figure 5 shows the changes in the number of days in the General Comfort Zone in Zhanjiang City from 2000 to 2017. Finally, Figure 6 shows the changes in the number of days under the broad classification of feeling cold in Zhanjiang City from 2000 to 2017. According to Figure 3-6, the human comfort level in Zhanjiang from 2000 to 2017 is dominated by hot, followed by comfort, and finally cold. Among them, hot and relatively hot are the main elements in the Hot Zone; comfortable is the main element in the General Comfort Zone, and the main element is cool in the Cold Zone. Therefore, according to the classification of the degree of human comfort in Zhanjiang City from 2000 to 2017, the number of days of the overall experience can be listed as follows: Hot Zone (hot, relatively hot ≫ extreme hot) > General Comfort Zone (comfort > slightly hot, slightly cool) ≫ Cold Zone (cool > slightly cold ≫ cold).

2.3. Summary

Human comfort is one of the factors that measure the quality of staying in an outdoor space, and it is an essential factor that must be considered for outdoor space design. The collection and analysis of meteorological data in Zhanjiang from 2000 to 2017 reveal that the feeling of hot dominates the human body experience in Zhanjiang’s outdoor spaces. In this case, the primary goal of improving the human body comfort in Zhanjiang City is to improve people's thermal comfort in outdoor spaces. The central meteorological factor that affects human comfort in a thermal environment is solar radiation intensity. Trees can reduce solar radiation intensity through shading to improve human comfort in small spaces [15-16]. Therefore, the most reasonable shading area is obtained by arranging the trees in the outdoor space, thus improving outdoor rooms' human body comfort in Zhanjiang City.

3. The model for tracking shadow changes of coconut palms

3.1. Reasons for choosing coconut palms.

The landscape architecture style of Zhanjiang City is based on Min's classification of zonal landscape architecture, which meets the essential characteristics of tropical gardens [17]. As a representative plant of tropical gardens, palms have straight stems, beautiful leaves, and distinctive zonal characteristics. They are indispensable plants for building tropical gardens. In the application survey of palm plants in the landscape architecture in the past five years, the coconut palm, as a typical palm plant, is used more frequently in the construction of tropical gardens and is best able to reflect the zonal characteristic plants of the tropical garden [18-19]. Thus, arranging coconut plants can form a highly comfortable outdoor activity space and create a tropical garden atmosphere.
Plant species' determination can form a unique landscape atmosphere, whereas individual plant specifications and arrangements affect the human comfort of the space. By selecting the coconut plant's specifications, one can more accurately establish the shadow change trajectory model. However, plants are living objects, and they will continue to grow as time passes. That means that plants with different growth years have different individual specifications. To ensure that plants' arrangements can effectively improve the comfort of the space, selecting the plant specifications is mainly based on combining the plants whose growth state has stabilized during the mature period with the plant canopy structure, which affects comfort. In the Flora of China, a coconut's appearance is described as follows: the plant is 15–30 meters high, the leaves are pinnately split, and the length of the leaves is 3–4 meters. In the study of Guixiang Jin et al. [20], it was found that the canopy structure of the forest—such as the crown height, crown height ratio, canopy thickness, and canopy permeability of trees—is correlated with the understory comfort. Accordingly, the study proposed that a lower canopy layer thickness (around 7.4 m) and more insufficient understory space (approximately 2.7 m) are conducive to improving comfort. Consequently, combining the description of the appearance of mature coconut plants from the Flora of China with the influence of canopy structure on comfort, we infer that the individual specifications of the coconut plants in the coconut planting arrangement should be 15 m in plant height, 3.7 m in leaf length, and 0.3 m in the diameter of the branch.

3.2. Analysis of sun's orbit based on the choice of geographic latitude and time

To establish the tracking model for shadow changes of coconut palms, it is also necessary to know the sun's path during the year. The process of obtaining the sun’s path for 365 days is cumbersome and unnecessary. The regular sun’s route shows that the sun’s direct rays move back and forth in a specific earth range. The north-south boundaries of this range on the earth are the Tropic of Capricorn and the Tropic of Cancer, while the sun’s direct rays reach the Tropic of Cancer on the summer solstices and Tropic of Capricorn on winter solstices. During this period, the sun’s direct rays reach the equator twice at the vernal equinox and autumnal equinox. Thus, we calculate the solar altitude angle and solar azimuth angle of the four solar terms such as the vernal equinox, summer solstice, autumnal equinox, and winter solstice, obtaining a simplified model of the sun’s trajectory in a year.

The longitude and latitude of Zhanjiang are between 109°31’–110°55’ east longitude and 20°–21°35’ north latitude. We take Zhanjiang’s longitude and latitude as 110° east longitude and 21° north latitude for the convenience of calculation.

Combining the calculation formula of the solar altitude angle and solar azimuth angle, we obtain this formula:

\[
\begin{align*}
\sin H_e &= \sin \varphi \cdot \sin D_E + \cos \varphi \cdot \cos D_E \cdot \cos T_0 \\
\cos A &= \frac{\sin H_e \sin \varphi - \sin D_E}{\cos \varphi} \\
\sin A &= \frac{\cos D_E \sin T_0}{\cos H_e}
\end{align*}
\]

In the formula, \(H_e\) is solar altitude angle; \(A\) is solar azimuth angle; \(\varphi\) is local latitude; \(D_E\) is Declination; \(T_0\) is Hour Angle. Among them, formulas (5) and (6) are derived based on the azimuth angle of due south direction being 0°, and the angle change gradually increases from the counterclockwise direction [21].

Table 2 shows the solar altitude angle and solar azimuth angle changes of the vernal equinox, summer solstice, autumnal equinox, and winter solstice. In Table 2, although the solar altitude and azimuth calculation are based on the apparent solar time in Zhanjiang, the Chinese’s use time is based on the mean solar time, which is the Beijing time at 120° east longitude. The purpose of the research is to construct a comfortable outdoor activity space. Thus, in the time column of Table 2, we enumerate the Beijing time corresponding to the solar altitude and solar azimuth in Zhanjiang instead of Zhanjiang local time, which will help more accurately activate the vitality of the venue. Figure 7 shows the sun's path from the spring equinox, Autumnal equinox, summer solstice, and Winter solstice.
Table 2. Solar altitude angle and solar azimuth angle changes.

| Solar term time a | vernal equinox | summer solstice | autumnal equinox | winter solstice |
|-------------------|---------------|-----------------|------------------|----------------|
|                   | $H_s$ b       | Ac              | $H_s$ A          | $H_s$ A        |
| 5                 | -26.31        | 260.48          | -15.41           | 241.49         |
| 6                 | -10.61        | 266.41          | -0.77            | 247.93         |
| 7                 | 7.55          | 272.54          | 16.09            | 253.15         |
| 8                 | 18.36         | 276.38          | 24.26            | 255.14         |
| 9                 | 31.90         | 282.02          | 37.96            | 257.89         |
| 10                | 44.19         | 288.98          | 53.38            | 260.08         |
| 11                | 58.37         | 302.90          | 67.59            | 260.64         |
| 12                | 68.01         | 325.96          | 82.01            | 253.29         |
| 13                | 68.94         | 29.67           | 87.17            | 138.66         |
| 14                | 62.18         | 50.64           | 71.72            | 99.84          |
| 15                | 47.20         | 68.82           | 53.86            | 99.87          |
| 16                | 37.21         | 75.28           | 45.56            | 100.90         |
| 17                | 23.81         | 81.51           | 31.69            | 103.28         |
| 18                | 10.78         | 86.35           | 16.44            | 106.76         |
| 19                | -5.44         | 91.82           | 3.13             | 110.70         |
| 20                | -21.62        | 97.62           | -9.99            | 115.85         |

\(a\) 24-hour clock
\(b\) solar altitude angle
\(c\) solar azimuth angle

3.3. Construction of shadow change track model of palm coconut based on sun’s path

After establishing the sun's path on the four classic solar terms in a year, the shadows formed by the tree crowns of coconut palms can be calculated and analysed, and a shadow change track model of palm coconut can be established. The canopy of each coconut tree is unique. It is necessary to find commonality in each coconut, with their independent characteristics, to establish a model to track shadow changes of coconut palms. After analysing the morphology of the common coconut tree crown, most coconuts are composed of straight trunks and leaves arranged radially at the centre top of the trunk. Therefore, the shape of coconut trees can be simplified into a combination of spherical and cylindrical shapes. Moreover, its cross-section consists of a circle and a rectangle, and Figure 8 shows a simplified coconut model. According to Figure 9—which shows the simplified coconut cross-section model, the solar altitude angle ($H_s$), and the solar azimuth angle ($A$)—the shadow area calculation formula can be obtained:

\[
S_a = S_b + S_c
\]
\[
S_b = A_1O_1 \cdot C_1O_1 \cdot \pi = \pi \cdot AO \cdot CO \cdot \frac{\sin(A-90^\circ)}{\tan H_s}
\]
\[
S_c = F_1F \cdot E_1F = F_1F \cdot EF \cdot \sin(A - 90^\circ) / \tan H_s
\]

Figure 7. Sun path diagrams of the vernal equinox, summer solstice, autumnal equinox, and winter solstice.
Figure 8. Coconut simplified model.  

Figure 9. Simplified cross-section model of coconut.

In the formula, \( S_\text{a} \) is total shadow area, \( S_\text{b} \) is Canopy shadow, \( S_\text{e} \) is tree trunk shadow, \( A_1O_1 \) is, \( C_1O_1 \) is, \( AO \) is the length from the center of the coconut crown in the simplified coconut cross-section model along the direction parallel to the horizontal plane to the edge, \( CO \) is the length from the center of the coconut crown in the simplified coconut cross-section model along the direction perpendicular to the horizontal plane to the edge, \( F_1F \) is the width of the trunk of coconut in the simplified coconut cross-section model, \( E_1F \) is the projection length from the intersection of the coconut tree canopy and the trunk to the bottom of the trunk in the simplified coconut cross-section model, \( EF \) is the length from the intersection of the coconut tree canopy and the trunk to the bottom of the trunk in the simplified coconut section model. Due to the sun's direct projection, the value of the included angle \( A \sim 90^\circ \) formed by the cross-section and the sun at any time is equivalent to 90° [22]. Thus, the shaded area of coconut is expressed as follows:

\[
S_\text{a} = S_\text{b} + S_\text{e} = \pi \cdot AO \cdot \frac{CO}{\tan H_2} + F_1F \cdot \frac{EF}{\tan H_2}
\]  

(10)

According to the sun's path, the simplified model of the coconut, and the formula of shadow area, we obtain Figure 10, Figure 11, Figure 12, and Figure 13. Among them, Figure 10 shows the model of the changes in the coconut shadow trajectory between 8 a.m. and 5 p.m. in the four, classic solar terms. Figure 11 provides the changes in the shadow area of the coconut trees at four classic solar terms. Figure 12 displays the changes in the shadow area of the coconut tree trunk at four classic solar terms. Finally, Figure 13 shows the changes in the shadow area of the coconut tree canopy at four classic solar terms.

Figure 10. The model of the coconut shadow trajectory change between 8 o'clock and 17 o'clock in the four classic solar terms.
According to the chart above, we obtain three principles governing changes in coconut shadows.

First, the farther the shadow is formed from the coconut plant, the larger the shadow area. Second, the shadow is closest to the plant around noon, and the shadow space created the smallest during the day. The tiniest shadow area in the entire year occurs when the sun’s position is directly above the plant; specifically, when the solar azimuth angle is 0° and the solar altitude angle is 90°, the shadow area is about 43 square meters at this time. Third, in the change of the coconut shadow area between 8 a.m. to 5 p.m. throughout the year, the rate of the shadow area change (the degree of increase or decrease of the shadow area over time) is arranged in descending order of summer solstice, the vernal equinox, autumnal equinox, and winter solstice.

4. Research on coconut planting method

4.1. The demand of human activity and percentage of shadow area in planting area

In this research, the coconut planting arrangement method is based on the climate characteristics of Zhanjiang City, which is discussed to improve the climate and thermal comfort level of outdoor spaces in Zhanjiang City. Therefore, the planting arrangement method needs to meet the following conditions: (1) provide room to improve the thermal comfort of the human body; and (2) have enough comfortable space for social activities.

In the outdoor space, a semi-shaded or full-shaded environment can provide a space that improves the thermal comfort level of the human body [7]. Analogical reasoning shows that the space formed by the shadow area will be the main space for social activities. The shaded area will change with time—meaning the comfortable space formed by the coconut is time-variable. Therefore, to ensure that the
ratio of the shadow area to the total space unit area is available for human activities, the smallest shadow area formed by an individual coconut in a year should be considered. According to the model that tracks the shadow changes of the coconut palms, when the sun’s position is directly above the plant—making the shadow area the smallest during the year—the solar azimuth angle is 0°. The solar altitude angle is 90°, and the shadow area is about 43 square meters. After obtaining the minimum area of the shadow space, it is also necessary to determine the space unit's proportion of human activity space.

The space of the coconut configuration model unit can be regarded as a binary habitat. We use the four-neighbor rule in the penetration theory to determine the statistical threshold of the habitat connection degree. The critical point of the square habitat unit under the four-neighbor law is 0.5928. Therefore, the critical threshold phenomenon reveals that the shadow area should account for about 60% or more of the coconut planting space area. Consequently, the size of the space occupied by X coconuts should be equal to or less than \( 43 \times X / 60\% = 71.6 \times X \text{ m}^2 \) (11).

4.2. Coconut planting method

After determining the area of the coconut planting unit, which corresponds to the number of coconuts, the next step is to determine the arrangement and number of coconuts in the space. As mentioned above, the comfortable space formed by the coconut has time variability; specifically, the area created by the shadow of the coconut is not constant. Theoretically speaking, the arrangement of coconut planting only needs to ensure that the orthographic projection area of the coconut occupies 60% of the space to form a comfortable space and ensure that the human activities in the space are not affected. However, when the planting space is small, if the coconuts are randomly arranged and occupy 60% of the space, the shadow area formed by the coconuts arranged on the space boundary cannot be used all the time, making the shadow retention rate in the space is low. A reserved space can be set around the coconut planting space to solve a low shadow retention rate. Moreover, the coconut planting arrangement in the shadow space can be determined by the ratio of the reserved area to the shadow space. Figure 14 shows the relationship between reserved space and planting space.

![Figure 14](image)

**Figure 14.** The relationship between reserved space and planting space.

According to the principles obtained from tracking changes in the coconut shadow areas and the overall human body comfort levels in Zhanjiang, we conclude that summer, spring, and autumn require improved thermal comfort, and the demand in summer is the strongest. Therefore, adequate shadow size is needed more in summer and can be appropriately reduced in winter. Accordingly, Figure 15 shows the area of shadow area utilization. According to the division of the space, the vertical distance between the center of the coconut and each side is calculated as follows: \( AO = 16 \text{ m}; BO = 40 \text{ m}; CO = 11 \text{ m}; \) and \( DO = 29 \text{ m} \). Based on Formula (11), when the shadow space occupies 60% of the unit space area and the reserved space is setting, we obtain an expression for the number of coconuts in the planting space:

\[
F(X) = X \cdot 71.6 - \left( (OA + OC) + \sqrt{43 \times X} \right) \cdot \left( (OB + OD) + \sqrt{43 \times X} \right)
\] (12)

![Figure 15](image)

**Figure 15.** The area of shadow area utilization.
According to the formula, the function image of the expression is shown in Figure 16. The meaning of this function is that when \( F(X) = 0 \), the ratio of the shadow area formed by the coconut to the space unit is equal to 60%. Moreover, when \( F(X) > 0 \), the shadow area formed by the coconut occupies less than 60% of the space unit. When \( F(X) < 0 \), the ratio of the shadow area formed by the coconut to the area of the space unit is greater than 60%. Where \( X_1 = 607.78 \) and \( X_2 = 6.98 \), \( F(X) = 0 \) means that the shadow area formed by coconut planting is equal to 60% of the space unit. Finally, when \( X = 307.38 \), the function obtains the minimum value. Because this formula is designed to solve the problem of low shadow retention rate in the small space formed by the coconut planting arrangement, if the shadow area in the space reaches 60% of the planting unit area, \( X = 6.98 \), and the final \( X = 7 \) trees (because the number of coconuts cannot be decimals).

The final coconut planting arrangement is as follows: (1) when the planting number is less than or equal to seven or greater than or equal to 608, the method of setting reserved space can be adopted, and the coconut planting arrangement is compact; and (2) when the number of coconuts is more significant than seven and less than 608, no dedicated space will be set, the arrangement of coconuts is random at this time, and the area of the planting space unit is less than or equal to 71.6\( \times X \) m\(^2\).

5. Discussions
Our study first sorted the daily meteorological data of Zhanjiang City from 2000 to 2017, calculated the overall change in the grade of human comfort in Zhanjiang City from 2000 to 2017 based on the golden section method, and obtained a direction for improving human comfort in Zhanjiang's outdoor spaces. Second, through the selection of representative plants in tropical gardens and the shadow space analysis from the spring equinox, autumnal equinox, summer solstice, and winter solstice, we obtained a model to track shadow changes of coconut palms. Meanwhile, according to the comfortable space requirement of outdoor human activities and the penetration threshold theory, the sunshine area should occupy 60% or more of the planting space unit area. Finally, combined with the shadow space retention rate and the model for tracking shadow changes of coconut palms, the following coconut planting arrangement is derived: (1) when the planting quantity is less than or equal to seven or more than 608, there is a reserved space, and the planting arrangement of coconuts is compact; and (2) when the number of coconuts is more than 7 and less than 608, there will be no reserved space. Currently, the planting arrangement of coconuts is random, and the area of planting space units is less than or equal to 71.6\( \times x \) m\(^2\) (\( x \) is the number of coconuts).

The research ideas of this study provide a guiding direction for the climate adaptability design of specific spaces of landscape architecture. Simultaneously, this paper also has many limitations. This study only considers how plants can improve the thermal comfort level in the space through shading and the impact of this single factor on human comfort —ignoring the impact of wind direction and wind speed on human comfort. It is hoped that subsequent researchers can conduct further research on this topic.

Acknowledgements
This paper was funded by the National Undergraduate Innovation and Entrepreneurship Training Program. (Project Number:201910566008).

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