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Effect of Greening Trees on Thermal Comfort of the Pedestrian Streets in Hot Summer and Cold Winter Regions in China

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ABSTRACT

The thermal environment problems of pedestrian streets space are becoming increasingly important with the growing rate of urbanization, especially in regions with hot summers and cold winters. Taking Cinnamomum camphora as an example, several urban design scenarios with dynamic setting parameters of streets orientation (N-S, E-W), aspect ratio (0.5, 1,1.5, 2) are simulated by ENVI-met to analyze the impact of the green coverage on the thermal comfort of the street canyons in Shanghai. Results showed that: (1) green coverage has an impact on the thermal comfort of the street both in summer and winter and the significance of this effect is affected by the orientation and aspect ratio of the streets. (2) In summer, with the increase in aspect ratio, N-S orientation streets need more and more green coverage to bring a significant impact on thermal comfort, while E-W orientation streets only need 24 % green coverage. (3) In winter, with the increase in aspect ratio, N-S orientation streets also need more green coverage to significantly reduce thermal comfort. For E-W orientation, only when the aspect ratio is 1/2, the green coverage can effectively reduce the thermal comfort of the street. (4) The planting layout had no significant effect on the thermal comfort effect of trees. Based on the above conclusions, the greening strategy was proposed for pedestrian streets in the hot summer and cold winter region in China.

INTRODUCTION

The thermal comfort of urban street space is related to people's comfortable experience of outdoor activities (Lee et al. 2018, Zhu et al. 2020). This is particularly evident in the pedestrian street space, because people are not just for traffic, but will stay, talk and hang out on foot, which will prolong people's stay time in the pedestrian street.

The thermal comfort of street space has been widely discussed by many scholars. Yahia & Johansson (2014) discussed the advantages and disadvantages of different urban design patterns in Damascus and argue that efficient use of vegetation positively affects the thermal environment. Deng et al. (2016) found that deep street canyons with higher aspect ratios reduce solar access and air temperature. In a study conducted by Rodriguez Algeciras et al. (2016), to achieve acceptable thermal comfort in the summer and winter seasons, the value for this design factor (aspect ratio) was suggested as 1 and 1.5. Achour-Younsi & Kharrat (2016) discussed the impact of the geometry of an urban street canyon on outdoor thermal comfort and found that the deepest streets are the most comfortable. Abdollahzadeh & Biloria (2021) evaluated the thermal performance of streets in residential zones of Liverpool, NSW, Australia, and found that street canyon orientation is the most influential factor, followed by aspect ratio.

Landscape elements such as trees, waterscapes, and shading facilities play a positive effect on the regulation of thermal comfort (Soares et al. 2021, Zhao & Fong 2017). However, research mainly focuses on the influence of street space morphology (e.g., orientation, aspect ratio, sky view factor, and surface conditions) at the present stage, ignoring the role of streetscape (Li et al. 2020). The spatial morphology of the street is more stable and difficult to be changed, but the streetscape can be easily modified (Yang et al. 2018). Moreover, these studies mainly focus on the summer season, and there is a lack of studies that take into account both summer and winter. Therefore, the study of the influence of street landscapes on thermal comfort in different seasons should be taken seriously.

Table 1 shows the relationship between the values of PET and heat feeling. The thermal comfort model is divided into an eight-point scale by combining physiological parameters and environmental parameters. Based on the human body's energy balance, PET is matched to the human biometeorological evaluation of the thermal component in each different climate. According to the literature reviewed, although PET is not proposed for the climate in China, it can still be an effective evaluation index for thermal comfort in China. In China's cold (Lai et al. 2014), hot summer and cold winter (Rupp et al. 2015), and hot summer and warm winter (Li et al. 2016) climate zone, PET has been proven to be applicable.

Shanghai is located in the hot summer and cold winter climate region in China. As the economic center of China, it has a wide variety of pedestrian streets. Tree planting patterns in pedestrian streets are more diverse, but the effect of trees on thermal comfort in pedestrian streets is unclear. In this study, we will use ENVI-met as a simulation tool to explore the impact of greening trees on the thermal comfort of pedestrian streets (Hu et al. 2021). The objectives of this study are to (1) explore the influence of green coverage on the thermal comfort of pedestrian streets in summer and winter under different street orientations and aspect ratio conditions. (2) Analyze the influence of planting layout on the thermal comfort effect of trees. (3) Propose the landscape greening strategy for pedestrian streets.

MATERIALS AND METHODS

Study Area

Shanghai is located in the east of China at a longitude between 120.5°E and 122.1°E and latitude between 30.4°N and 31.5°N. In summer, the average daytime air temperature is 26°C and the mean relative humidity is 77%. The mean wind speed is 3.2 $m.s^{-1}$ and the primary wind direction is southeast. In winter, the average daytime air temperature is 18°C and the mean relative humidity is 65%. The mean wind speed is 3.0 $m.s^{-1}$ and the primary wind direction is northwest. July and January are the hottest and coldest months respectively in Shanghai.

Construction of Simulation Models

Tree model

Table 1: PET value and thermal perception.

PET(°C)	Human Subjective Comfort Feeling
<4	Very Cold
4-8	Cold
8-13	Cool
13-18	Slightly Cool
19-23	Neutral
23-29	Slightly Warm
29-35	Warm
35-41	Hot
>41	Very Hot

Leaf Area Index (LAI) can describe an area or a plant's overall degree of lushness (Cao et al. 2021). Changes in the LAI can contrast different degrees of greening. LAD is defined as the ratio of the total leaf area to the unit volume in different levels of the canopy. LAD can describe the leaf density and the distribution of a plant (Ng et al. 2012). Where the LAD is 0, it means the trunk is in this area.

$$\mathrm{LAI} = \int_0^H LAD \cdot \Delta h \qquad (1)$$

Where H (m), Height of the vegetation; Δh (m), Vertical Grid Size; LAI, Leaf Area Index; LAD ($m.^2.m^{-3}$), Leaf Area Density

In this study, the evergreen tree species *Cinnamomum camphora* (L.) Presl., which is widely grown in Shanghai, was modeled. The tree's height of 10 m was ideal for the Shanghai street's urban design pattern. According to the measurement results of Gao et al. (2010), the LAI value of *Cinnamomum camphora* was set to 3.8 both in summer and winter. The vertical grid size was set to 1m and the LAD value (from top to bottom) of the model is calculated according to Eq. (1), as shown in Fig. 1. The remaining conditions adopt the default values of the system.

Street Model

The setting of the aspect ratio of streets refers to the actual size of Shanghai pedestrian streets and related architectural design guidelines (Abdollahzadeh & Biloria 2021). The width is set to 18 m, and the building models on both sides of the street are established according to four aspect ratios (0.5, 1, 1.5, 2) (Fig. 2). The length of the street is set to 60 m. The green coverage of streets was estimated by the ratio of the vertical projection area of the tree crown to the street area. Increase the green coverage with a gradient of 12% (4 trees) based on a blank street (Fig. 3). To simplify the experimental process, this study only modeled the streets in the east-west (E-W) and north-south (N-S) orientations.

Simulation by ENVI-Met

A model domain with a 60 × 60 × 30 grid version was applied in the simulations. The grid sizes for the site were set to be 2 m. In addition, 10 nesting grids were added around the model to improve simulation accuracy (Yang et al. 2020). The simulation was carried out on the 15th of July since this day is more or less in the middle of the three hottest months in summer, and the day 15th of January was studied to represent the winter season because it is in the middle of the three coldest months. The simulated period lasted from 9:00 local time (LT) in the morning until 16:00 LT in the afternoon including the time period with obvious sunshine. The main parameters used in the summer and winter simulations are shown in Table 2.

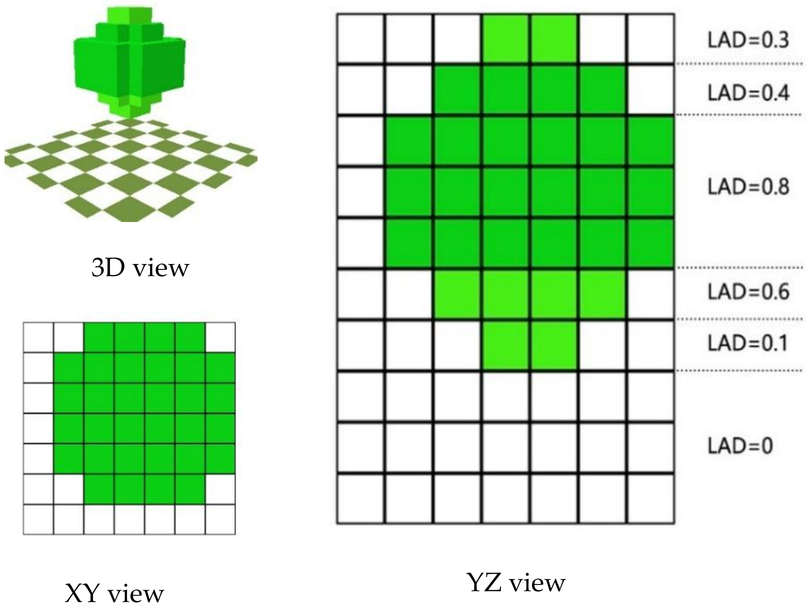


Fig. 1: Description of the tree model.

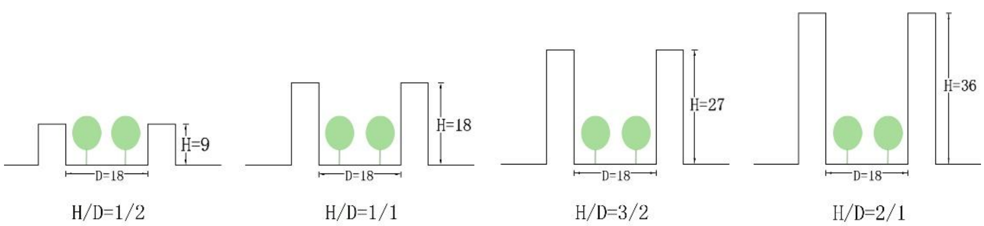


Fig. 2: Description of the aspect ratio of the street(m).

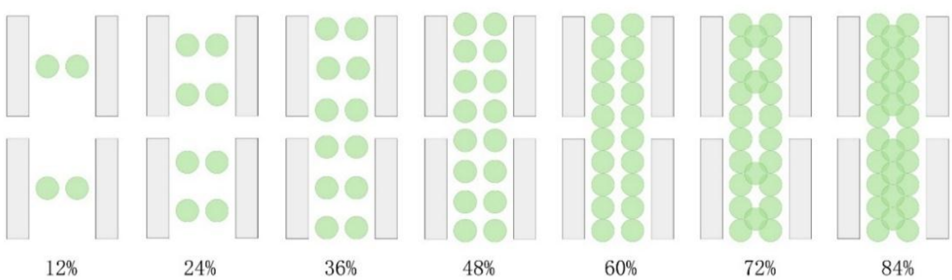


Fig. 3: Planting layout of the tree and its corresponding green coverage.

RESULTS

Effect of Green Coverage on PET in Summer

Characterization of PET

Fig. 4 shows the relationship between green coverage and the PET means (9:00-16:00) of the streets in summer. It can be found that as the green coverage increases, the PET values of the streets all tend to decrease, and this trend tends to level off after the green coverage reaches 60%. The PET values of E-W orientation street are higher than that of N-S orientation street under the same green coverage, and the gap between the two increases with the increase of street aspect ratio.

With the increase of the aspect ratio, the influence of the green coverage on the PET becomes smaller, which is particularly obvious in the N-S orientation street. With the increase of green coverage, the standard deviation of

Table 2: Main parameters input in the ENVI-met.

Simulation Parameters	Summer	Winter
Day	15 July	15 Jan
Time	9:00-16:00	9:00-16:00
Roughness length	0.1	0.1
Simple forcing: air temperature (K)	Min 298 at 6:00; max 305 at 16:00	Min 276 at 6:00; max 282 at 16:00
Simple forcing: relative humidity (%)	Min 70 at 16:00; max 85 at 6:00	Min 60 at 16:00; max 75 at 6:00
Wind speed at 10 m above ground level ($m.s^{-1}$)	3.2	3.0
Wind direction (◦)	135	315
Cloud cover	0	0
Materials of buildings and roads	Default settings in ENVI-met	Default settings in ENVI-met
Clothing parameters	0.3	0.9
Body parameters	Default settings in Biomet	Default settings in Biomet

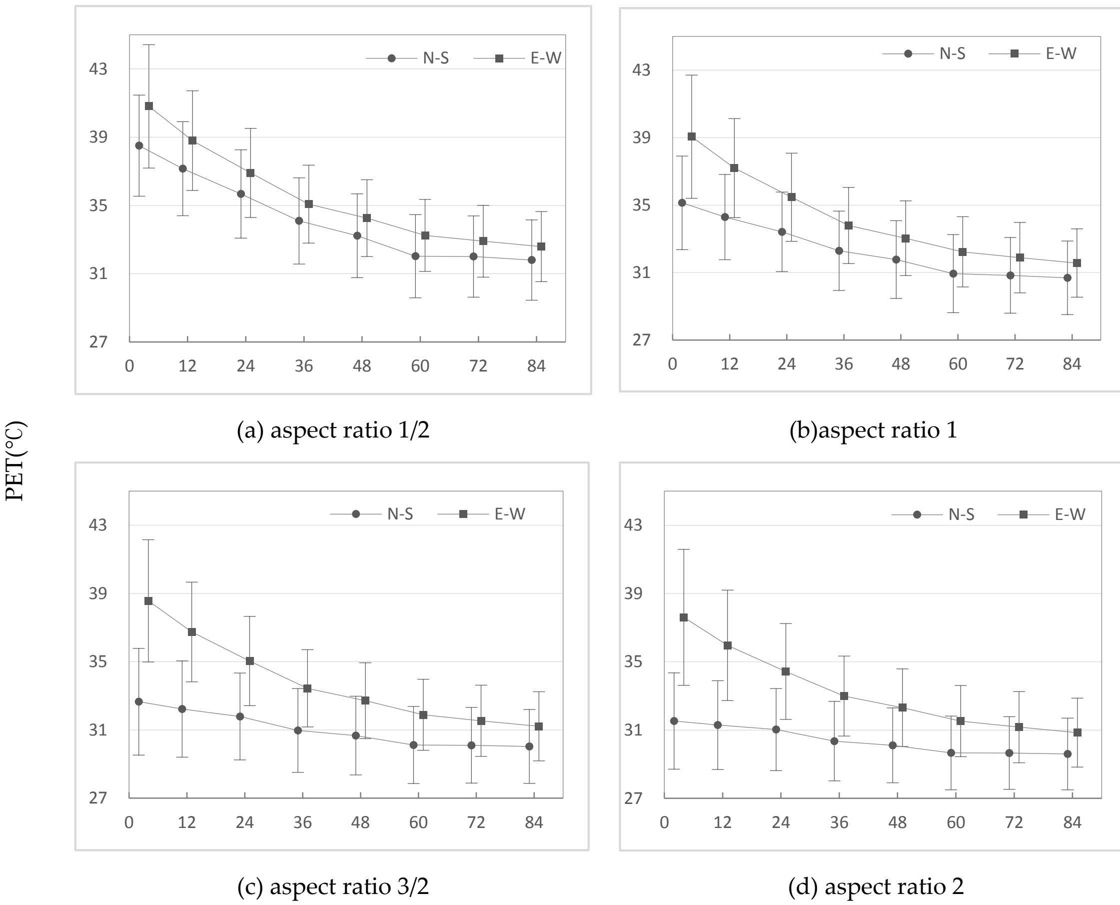


Fig. 4: Mean (9:00-16:00) and standard deviation of PET in summer.

PET values decreases, indicating that green coverage could stabilize thermal comfort in the daytime.

Difference Analysis of PET Means

The single-sample T-test method was used to analyze the differences in PET means between green streets and blank streets. The results are shown in Table 3. For the N-S orientation, with the increase in aspect ratio, more and more green coverage is needed to significantly reduce the PET means of the street. For the E-W orientation, regardless of the aspect ratio, 24% green coverage can significantly reduce the PET mean of the street. It can be seen that green coverage has more influence on the thermal comfort of the E-W orientation streets.

The Impact of Green Coverage on PET at Different Time Points

To analyze the difference in green coverage on PET at different time points, taking Table 1 as a standard, mark the greening coverage corresponding to the PET grade difference (relative to the blank street) at each time point. The results are shown in Figs. 5-6.

With the increase of aspect ratio, the time points that PET values have grade difference become less. Relatively speaking, the number of impacted time points in N-S orientation streets is less than in E-W orientation streets, which is consistent with the previous results.

For the N-S orientation, when the aspect ratio is less than or equal to 1, almost all time points will be affected effectively. When the aspect ratio is 3/2, only the PET values at 10:00, 13:00, and 14:00 are effectively affected. And when the aspect ratio reaches 2, only the thermal comfort at 10:00 is upgraded. For the E-W orientation, regardless of the aspect ratio, the thermal comfort of most time points has been improved. As the aspect ratio increases, green coverage has little effect on thermal comfort between 11:00 and 13:00.

Effect of Green Coverage on PET in Winter

Characterization of PET

Fig. 7 shows the relationship between green coverage and the PET means (9:00-16:00) of the street in winter. Although there is still a downward trend in the PET values with the increase of green coverage, this effect is relatively weaker

Table 3: The results of the single-sample T-test between green streets and blank streets.

Aspect ratio	Orientation	Green coverage						
		12%	24%	36%	48%	60%	72%	84%
1/2	N-S	.208	.017*	.002**	.001**	.000**	.000**	.000**
	E-W	.094	.004**	.000**	.000**	.000**	.000**	.000**
1/1	N-S	.376	.077	.011*	.004**	.001**	.001**	.001**
	E-W	.117	.006**	.000**	.000**	.000**	.000**	.000**
3/2	N-S	.683	.371	.095	.046*	.016*	.014*	.011*
	E-W	.121	.007**	.000**	.000**	.000**	.000**	.000**
2/1	N-S	.796	.570	.193	.108	.044*	.041*	.035*
	E-W	.193	.015*	.001**	.000**	.000**	.000**	.000**

Note: * Significance at the 0.05 level. ** Significance at the 0.01 level. The same is below.

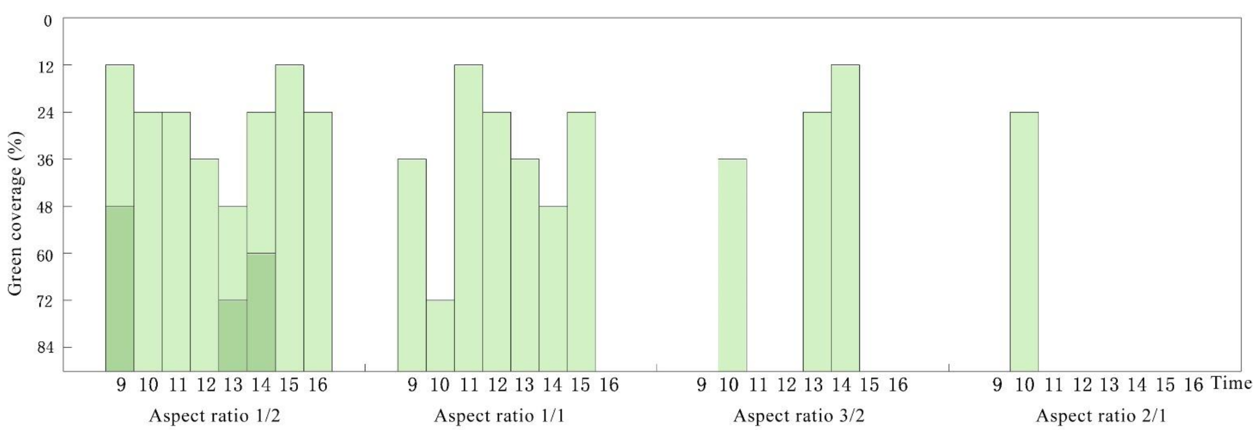


Fig. 5: The green coverage of N-S orientation streets when PET produces grade change.

Note: Light green: one-level difference; Dark green: two-level difference; Blank: no grade difference. The same is below.

than in summer and mainly affects the N-S orientation streets. Similarly, with the increase in aspect ratio, the impact of green coverage on thermal comfort is gradually weakened. For the E-W orientation, only when the aspect ratio is 1/2, the green coverage has an effective impact on the PET values. In addition, with the increase of green coverage, the standard deviation of PET values decreases. It can be seen that the green coverage also makes the thermal comfort of streets tend to be stable in winter.

Difference Analysis of PET Means

Table 4 shows the differences in PET means between green streets and blank streets. For the N-S orientation, when the aspect ratio is 1/2, starting with 24 % green coverage, the PET means can be significantly reduced. After the aspect ratio reaches 1, 36% green coverage is needed to make the PET mean decrease significantly. For the E-W orientation, only the street with an aspect ratio of 1/2 has a significant difference in PET mean starting from 24% green coverage. For streets with other aspect ratios, the green coverage does not have a significant impact on the thermal comfort of the streets.

The Impact of Green Coverage on PET at Different Time Points

Fig.8-9 shows the greening coverage corresponding to the PET grade difference (relative to the blank street) at each time point. In contrast to summer, the green coverage of N-S orientation streets has a greater influence on thermal comfort than N-S orientation streets in winter. The thermal comfort of the majority of time points has decreased when the aspect ratio is 1/2. The green coverage no longer significantly affects thermal comfort after the aspect ratio reaches 1 except between 10:00 and 14:00.

The Impact of Planting Layout Factors on PET

Whether the planting layout of trees has an impact on their thermal comfort effect? To make clear it, we took the street with an aspect ratio of 1/2 and 36 % green coverage as an example and summarized four planting layouts based on on-

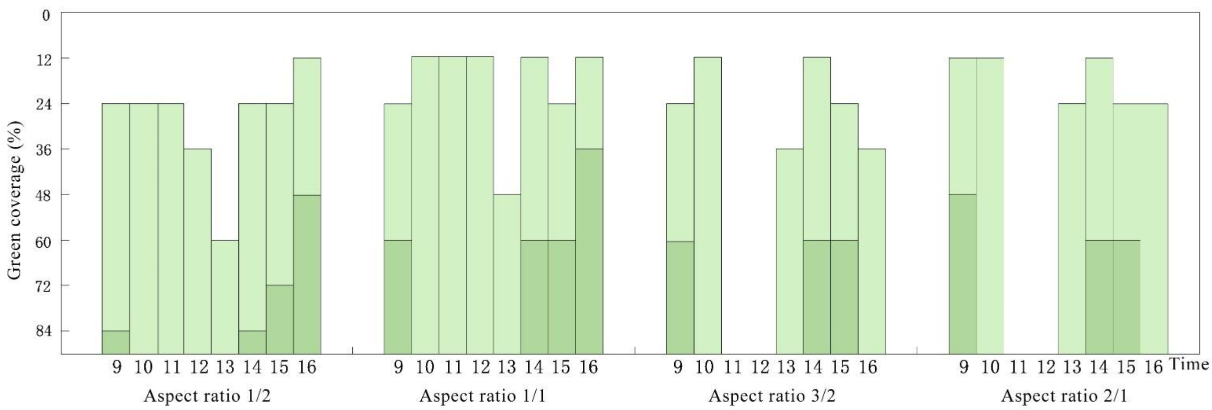


Fig. 6: The green coverage of E-W orientation streets when PET produces grade change.

Table 4: The results of the single-sample T-test between green streets and blank streets.

Aspect ratio	Orientation	Green coverage						
		12%	24%	36%	48%	60%	72%	84%
1/2	N-S	.061	.005**	.000**	.000**	.000**	.000**	.000**
	E-W	.278	.023*	.000**	.000**	.000**	.000**	.000**
1/1	N-S	.541	.151	.013*	.002**	.000**	.000**	.000**
	E-W	.451	.406	.493	.698	.587	.789	.891
3/2	N-S	.630	.205	.028*	.003**	.000**	.000**	.000**
	E-W	.530	.526	.742	.465	.277	.386	.439
2/1	N-S	.671	.239	.033*	.003**	.000**	.000**	.000**
	E-W	.570	.619	.877	.368	.191	.255	.292

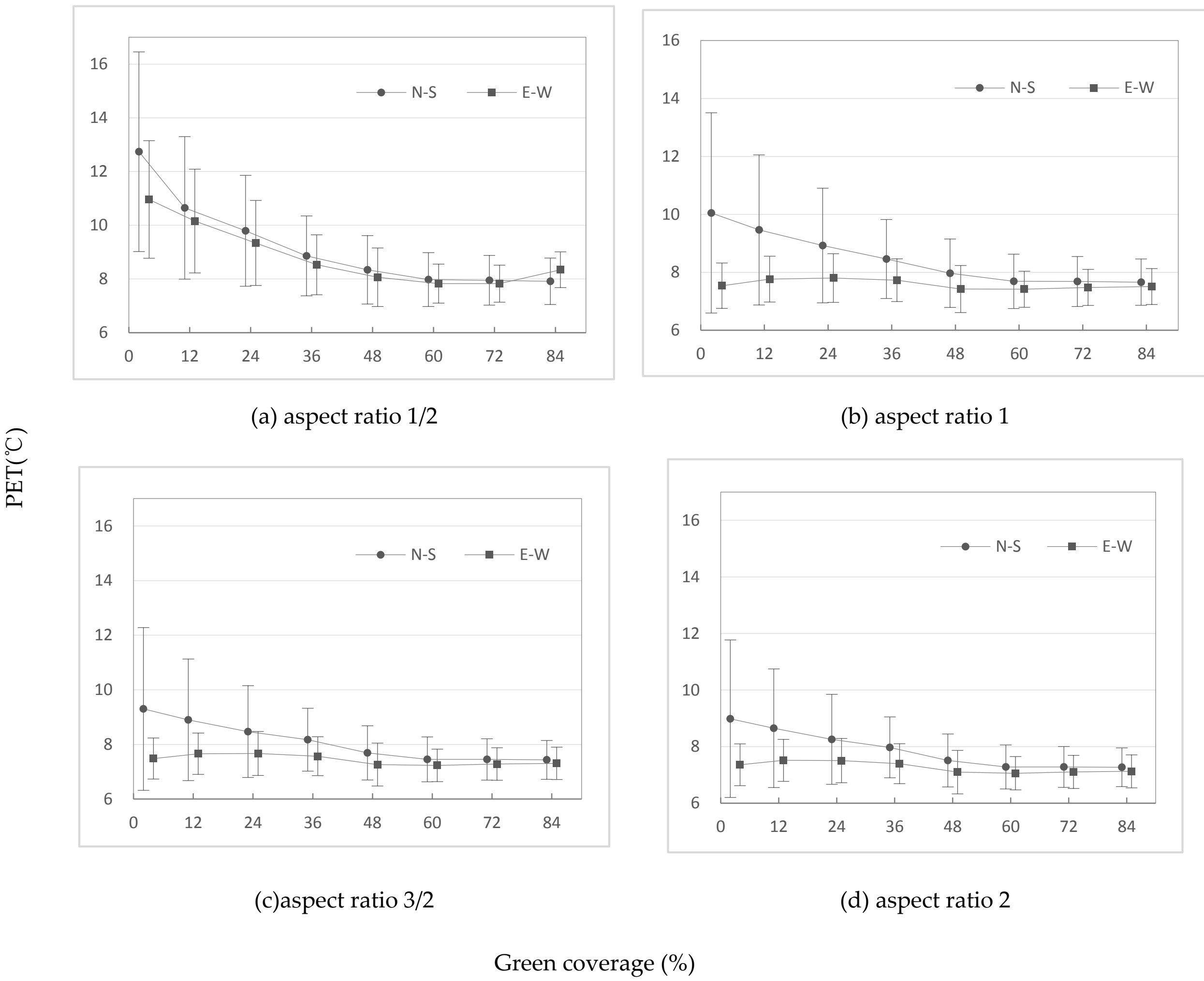


Fig. 7: Mean (9:00-16:00) and standard deviation of PET in winter.

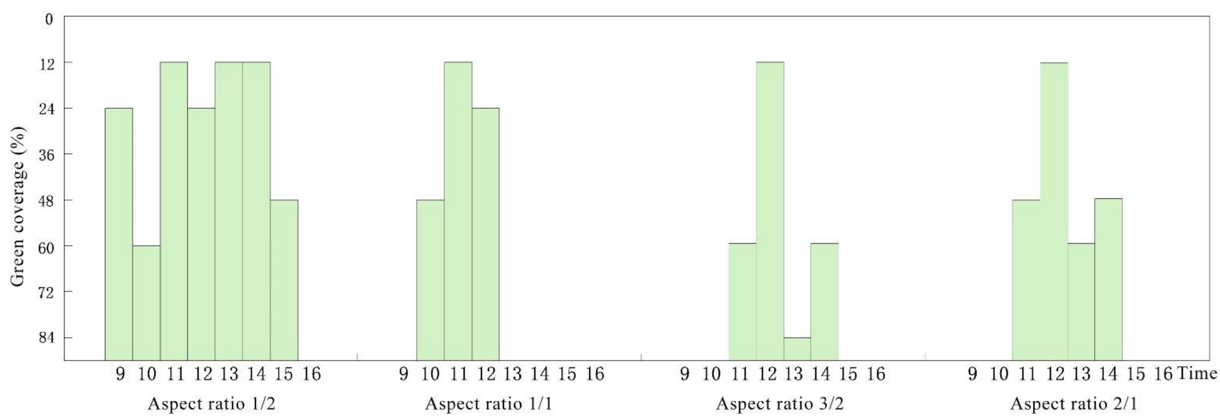


Fig. 8: The green coverage of N-S orientation streets when PET produces grade change.

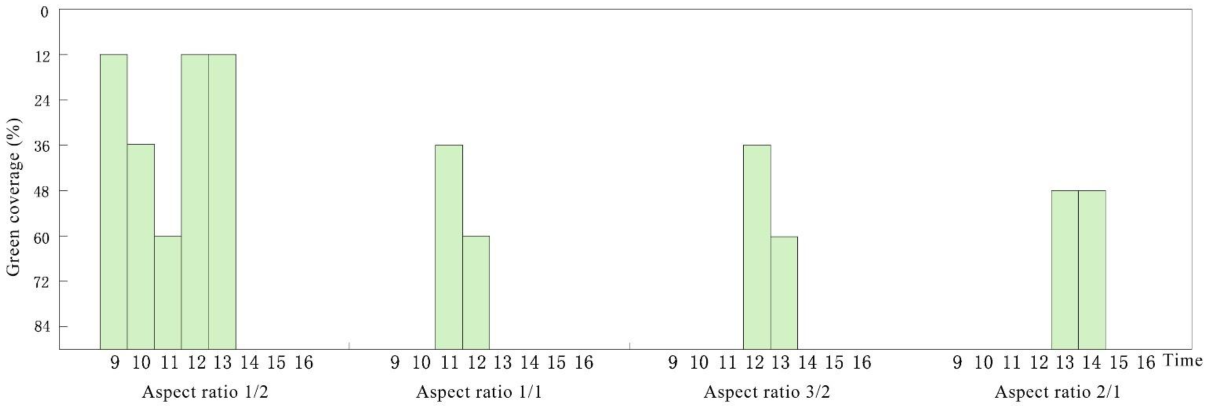


Fig. 9: The green coverage of E-W orientation streets when PET produces grade change.

site investigations on pedestrian streets (Fig. 10). The PET values of these four cases in different street orientations and seasons were simulated and calculated. Single-factor ANOVA analysis is used to analyze the difference in calculation results. The results are shown in Fig.11.

Fig. 11 shows that regardless of the street orientations and season, planting layouts cannot bring about significant differences in the thermal comfort effects of trees. For N-S orientation, in both summer and winter, the 'two-group' planting layout results in the highest PET values for the street, and the 'two-row-middle' planting layout results in the lowest PET values. For E-W orientation, in both summer and winter, the 'two rows side planting layout can make the street more suitable. But it should be pointed out that these differences are not significant.

DISCUSSION

Effect of Green Coverage on Thermal Comfort of Streets

The study found that tree greening has a positive impact on the thermal comfort of the street in summer, and a negative impact in winter. However, the significance of this effect is affected by the orientation and aspect ratio of the street.

In summer, tree greening has less influence on thermal comfort in N-S orientation streets than in E-W orientation streets. with the increase in aspect ratio, the N-S orientation streets need more and more green coverage is needed to significantly improve the thermal comfort of the street, while E-W orientation streets only need 24 % green coverage. For the N-S orientation, building shadows on both sides can affect the thermal comfort of the street. For the E-W orientation, only the shadows of the building on the south side can affect the thermal comfort of the street. This is the main reason why the N-S orientation streets can provide better thermal comfort (Srivanit & Jareemit 2020). However, more building shadows cover trees, which weakens the blocking effect of trees on light, resulting in a reduction in the plant's regulation of thermal comfort(Zheng et al. 2020). That's why the influence of trees in N-S orientation streets is weaker than that in E-W orientation streets. Similarly, with the increase

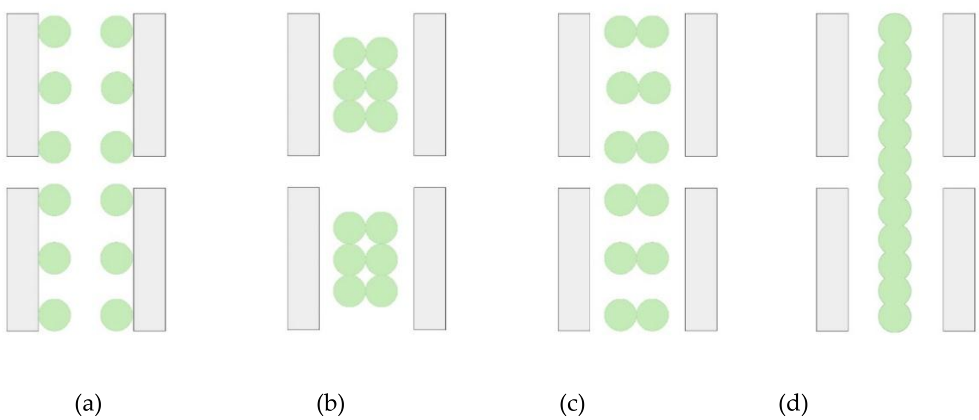
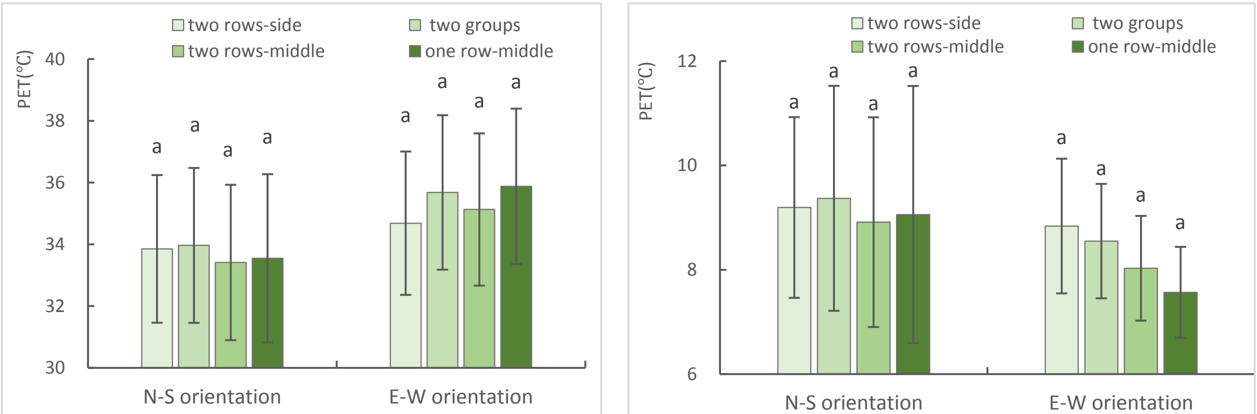


Fig. 10: Four planting layouts of trees: (a) two rows-side; (b) two groups; (c) two rows-middle; (d) one row-middle



(a)summer (b)winter

Fig. 11: Difference in thermal comfort effect of four planting layouts.

of the aspect ratio, the shadow range of buildings on both sides of N-S orientation streets expands, and more trees are covered by building shadows. Therefore, more trees are needed to effectively regulate the thermal comfort of the street. In contrast, the building shadow range on the E-W orientation streets changes little. No matter what the aspect ratio is, 24 % of the green coverage can effectively improve thermal comfort.

On the contrary, in winter, tree greening has a bigger influence on thermal comfort in N-S orientation streets than in E-W orientation streets. This is also because of the impact of building shadows on trees. In winter, the direct angle of sunlight becomes smaller, resulting in a larger shadow range of the building. The shadow of the building on the south side of E-W orientation streets easily covers the whole street. That's why for E-W orientation, green coverage can only effectively improve the thermal comfort of streets with an aspect ratio of 1/2. For S-W orientation, although the shadow range of buildings is also expanded in winter, the streets have sufficient light at noon (11:00-14:00), and trees can effectively reduce the thermal comfort of this time period.

In addition, the study found that the planting layout had no significant effect on the thermal comfort effect of trees. The shading effect of the canopy is the main reason trees regulate thermal comfort(Chen et al. 2021, Speak et al. 2021). However, different planting layouts will not have a significant impact on the shade range of trees under the condition of a certain number of trees. So there is no significant difference in the thermal comfort effect brought by different tree planting layouts.

Greening Strategy for Pedestrian Streets

For the N-S orientation, to get a more suitable thermal feeling in summer, the larger the aspect ratio of the street, the more trees need to be planted. The specific relationship between green coverage and aspect ratio can be referred to in Table 1. But inevitably, evergreen trees such as camphor trees also reduce the thermal comfort of streets in winter. Therefore, for the N-S orientation streets, planting deciduous trees is a more appropriate choice. This ensures that the thermal comfort of the streets in winter is not significantly reduced.

For the E-W orientation, in summer, when the green coverage reaches 24%, the thermal comfort of the street can be significantly improved. In winter, the green coverage has little effective impact on street thermal comfort (except for streets with an aspect ratio of 1/2). Therefore, for the sake of landscape effect, evergreen trees could be planted in E-W orientation streets.

In addition, the planting layout had no significant effect on the thermal comfort effect of trees. This suggests that we can design the planting layout of trees according to the landscape needs. At the same time, the green coverage of streets should be controlled by 60%.

Limitations and Future Research

In this study, only one type of evergreen tree was considered, and the influence of tree morphology such as tree height, LAI, and crown shape on the results was not considered. Many studies have found that the morphological variables of trees have an important impact on their thermal comfort effect (Cao et al. 2020, Wai et al. 2021). Besides green trees, landscape elements such as shrubs, waterscape, and shading facilities can also influence thermal comfort (Liu et al. 2021), which can continue to be explored in future street thermal comfort studies.

CONCLUSIONS

Taking Shanghai as an example, we used ENVI-met to simulate the impact of green coverage on the thermal comfort of pedestrian streets in summer and winter. Results showed that green coverage has an impact on the thermal comfort of the street both in summer and winter, and the significance of this effect is affected by the orientation and aspect ratio of the street. Overall, the PET value of the street decreases as the green cover increases. In summer, green coverage has more influence on thermal comfort in E-W orientation streets. With the increase in aspect ratio, N-S orientation streets need more and more green coverage to bring a significant impact on thermal comfort, while E-W orientation streets only need 24 % green coverage. Inversely, in winter, green coverage has a greater impact on thermal comfort in N-S orientation streets. With the increase in aspect ratio, N-S orientation streets need more green coverage to significantly reduce thermal comfort. For E-W orientation, only when the aspect ratio is 1/2, the green coverage can effectively reduce the thermal comfort of the street. The study also found that the planting layout had no significant effect on the thermal comfort effect of trees. Based on the above conclusions, the greening strategy was proposed for pedestrian streets in hot summer and cold winter regions in China.

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REFERENCES

Abdollahzadeh, N. and Biloria, N. 2021. Outdoor thermal comfort: Analyzing the impact of urban configurations on the thermal performance of street canyons in the humid subtropical climate of Sydney. Frontiers of Architectural Research., 10 (2): 394-409.

Achour-Younsi, S. and Kharrat, F. 2016. Outdoor Thermal Comfort: Impact of the geometry of an urban street canyon in a Mediterranean Subtropical Climate: Case Study Tunis, Tunisia. Procedia - Social and Behavioral Sciences., 216: 689-700.

Cao, L., Xu, H. and Li, H. 2020. Research on Residential Landscape Design Based on Microclimate Effect. Construct. Sci. Technol., (22): 84-88.

Cao, L., Xu, H. and Li, H. 2021. Numerical Simulation of the Influence of Landscape Plants on Human Thermal Comfort in Cold Season in Nanjing City. J. Northwest Frest. Univ., 36(05): 238-245.

Chen, T., Pan, H., Lu, M., Hang, J., Lam, C.K.C., Yuan, C. and Pearlmutter, D. 2021. Effects of tree plantings and aspect ratios on pedestrian visual and thermal comfort using scaled outdoor experiments. Sci. Total Environ., 801: 149527.

Deng, J., Wong, N.H. and Zheng, X. 2016. The study of the effects of building arrangement on microclimate and energy demand of CBD in Nanjing, China. Procedia Eng., 169: 44-54.

Gao, K., Qin, J. and Hu, Y. 2010. Correlation of leaf area index and morphological features for main evergreen broadleaf tree species in Shanghai City. J. Central South Univ. Forest. Technol., 30 (10): 34-40.

Hu, X., Yang, J., Feng, H. and Marvin, S. 2021. Verifying an ENVI-met simulation of the thermal environment of Yanzhong Square Park in Shanghai. Urban for Urban Gree: 127384.

Lai, D., Guo, D., Hou, Y., Lin, C. and Chen, Q. 2014. Studies of outdoor thermal comfort in northern China. Build Environ., 77: 110-118.

Lee, S., Moon, H., Choi, Y. and Yoon, D.K. 2018. Analyzing Thermal Characteristics of Urban Streets Using a Thermal Imaging Camera: A Case Study on Commercial Streets in Seoul, Korea. Sustainability-Basel., 10 (2).

Li, G., Ren, Z. and Zhan, C. 2020. Sky View factor-based correlation of landscape morphology and the thermal environment of street canyons: A case study of Harbin, China. Build Environ., 169: 106587.

Li, K., Zhang, Y. and Zhao, L. 2016. Outdoor thermal comfort and activities in the urban residential community in a humid subtropical area of China. Energy Build., 133: 498-511.

Liu, S., Zhao, D.J., Xu, M. and Ahmadian, E. 2021. Effects of landscape patterns on the summer microclimate and human comfort in urban squares in China. Sustain Cities Soc., 73: 103099.

Ng, E., Chen, L., Wang, Y. and Yuan, C. 2012. A study on the cooling effects of greening in a high-density city: An experience from Hong Kong. Build Environ., 47(1): 256-271.

Rodriguez Algeciras, J.A., Gomez Consuegra, L. and Matzarakis, A. 2016. Spatial-temporal study on the effects of urban street configurations on human thermal comfort in the world heritage city of Camagüey-Cuba. Build Environ., 101: 85-101.

Rupp, R.F., Vásquez, N.G. and Lamberts, R. 2015. A review of human thermal comfort in the built environment. Energy Build., 105: 178-205.

Soares, R., Corvacho, H. and Alves, F. 2021. Summer thermal conditions in outdoor public spaces: A case study in a Mediterranean climate. Sustainability, 13(10): 5348.

Speak, A., Montagnani, L., Wellstein, C. and Zerbe, S. 2021. Forehead temperatures as an indicator of outdoor thermal comfort and the influence of tree shade. Urban Climate, 39: 100965.

Srivanit, M. and Jareemit, D. 2020. Modeling the influences of layouts of residential townhouses and tree-planting patterns on outdoor thermal comfort in Bangkok suburbs. J. Build. Eng., 30: 101262.

Wai, K., Xiao, L. and Tan, T.Z. 2021. Improvement of the outdoor thermal comfort by water spraying in a high-density urban environment under the influence of a future (2050) climate. Sustainability, 13(14): 7811.

Yahia, M.W. and Johansson, E. 2014. Landscape interventions in improving thermal comfort in the hot dry city of Damascus, Syria: The example of residential spaces with detached buildings. Landsc. Urban Plan., 125: 1-16.

Yang, S., Zhou, D., Wang, Y. and Li, P. 2020. Comparing the impact of multi-factor planning layouts in residential areas on summer thermal comfort based on the orthogonal design of experiments (ODOE). Build Environ., 182: 107145.

Yang, Y., Zhou, D., Gao, W., Zhang, Z., Chen, W. and Peng, W. 2018. Simulation on the impacts of the street tree pattern on built summer thermal comfort in a cold region of China. Sustain Cities Soc., 37: 563-580.

Zhao, T.F. and Fong, K.F. 2017. Characterization of different heat mitigation strategies in the landscape to fight against heat islands and improve thermal comfort in a hot–humid climate (Part I): Measurement and modeling. Sustain. Cities Soc., 32: 523-531.

Zheng, S., Guldmann, J., Liu, Z., Zhao, L., Wang, J. and Pan, X. 2020. Modeling of shade creation and radiation modification by four tree species in hot and humid areas: A case study of Guangzhou, China. Urban Green., 47: 126545.

Zhu, Z., Liang, J., Sun, C. and Han, Y. 2020. Summer outdoor thermal comfort in urban commercial pedestrian streets in severe cold regions of China. Sustainability, 12 (5): 151.