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Study on the Microclimate Effect of Water Body Form in Urban Square

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ABSTRACT

In urban areas, water bodies have a positive effect on the microclimate of the surroundings. However, there is less information on the relationship between artificial water body forms and the microclimate, especially the artificial water bodies in urban squares. The study of the microclimate effect of the water body form and layout in the city square can provide the necessary reference for the design of a city square. This study first summarized the basic shape and area of the city square in Nanjing. Through the investigation of the water body form of the city square, two quantitative indicators of the water body were summarized: the water body area ratio and the water body shape index. According to these indicators, a series of different water body models were generated in the basic square model, which was used as the object of microclimate simulation. Using ENVI-met, simulations of city square models with different water forms were performed for a typical day of summer and winter, and their effects on thermal comfort were recorded. Through the statistical analysis of the simulation results, it was found that there is a clear correlation between the water body form indicators and the microclimate effects, although the microclimate effect intensity of different morphological indicators is different. The analysis results can provide a valuable reference for the design of city squares.

Introduction

In urban areas, water bodies have a positive effect on the surrounding microclimate (Manteghi et al. 2015). A number of studies have demonstrated the cooling effect of water on the surroundings through evaporation and convection, including large areas of lakes, rivers, or small ponds (Gupta et al. 2019, Masiero and Desouza 2012). However, most of the research aims at natural water bodies such as large lakes, rivers, or wetlands, with little attention to the smaller water bodies (Huang et al. 2008, Sun et al. 2012). Moreover, there is less information on the relationship between artificial water body form and microclimate (Jin et al. 2017). The natural water resources in cities are limited and fixed. In comparison, artificial water bodies, especially those in urban squares, are more common and can be controlled by urban design.

As an important part of public spaces, the city square has a very important influence on the life activities of the citizens (Chiesura 2004). Compared with other types of public spaces, such as parks or green spaces, the city square has its own characteristics. First, the city square is generally hard-paved to provide spaces for civic activities. Green spaces and water bodies, as part of the square, provide a richer visual landscape and effectively improve the microclimate, although this improvement is often not the main driver of the design but is merely a side effect. Second, the area of the city square is limited. The sum of the area of the hard paving, the green space and the water body is fixed. The area of green space and water should not be expanded indefinitely solely for microclimate effects. The proportion of water area in the square cannot be too high. Third, the

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evaluation of microclimate cannot be limited to the temperature, nor to the surrounding or downwind direction of the water body. We need to think more about human thermal comfort in the activity area of the square. Finally, unlike natural water bodies, water in city squares can be controlled by design. Therefore, through the study of the microclimate effect of the water body form and layout in the city square, it can provide the necessary reference for the design of the city square and is used to maximize the microclimatic improvement effect of these artificial water bodies.

Methodology

Urban Square Prototype

This study uses Nanjing, China as a study case. The city has a hot summer and cold winter. The citizens have many outdoor activities and are very sensitive to the outdoor microclimate environment. The microclimate effect of water bodies is also very significant for their activities. Based on the Baidu Map open data, we obtained data of all the squares in the main city of Nanjing. Through the investigation of the area, shape, surrounding road grades and construction conditions of these squares, we established the basic prototype of the urban square (Figure 1). The prototype measures 144 by 144 meters and is surrounded by 24 meter-wide urban roads. The surrounding blocks are uniformly distributed in 18 meter high, 36 or 42 meter long and 12 meter wide residential buildings. The buildings are set back from the road 6 meters. The buildings are 24 meters apart from north to south and 12 meters from east to west.

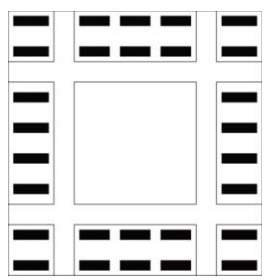


Figure 1. The prototype model of the square.

Water Body Prototype Models

The water in the urban square is mainly static. Therefore, the geometric form and spatial layout are the most important features of the water body and are affected by factors including water scale, dispersion, shape, and location. This study focuses on the analysis of the scale and shape of static water bodies.

The scale of the water body is the primary factor in the layout of water features. Different areas of water will give people a different sense of space. A small-scale water body is a space embellishment that enhances the quality of the space and creates a variety of spaces. A large-scale water body can become the center of the square. For the quantitative representation of the water body scale, we used the water area ratio, which is the ratio of the water area to the square area.

$$R = \frac{A_w}{A_s} \tag{1}$$

Where R is the proportion of water body area, A_w is the area of water body, and A_s is the total area of the square.

Figure 2 presents three cases with different R values. The left one is a water body of approximately 2,000 m^2, accounting for 10% of the total area of the square. The middle one is a water body of approximately 6,000 m^2, accounting for 30% of the square. Finally, the right one is a water body of Approximately 10,000 m^2, accounting for 50% of the square. These three were set as the study cases.

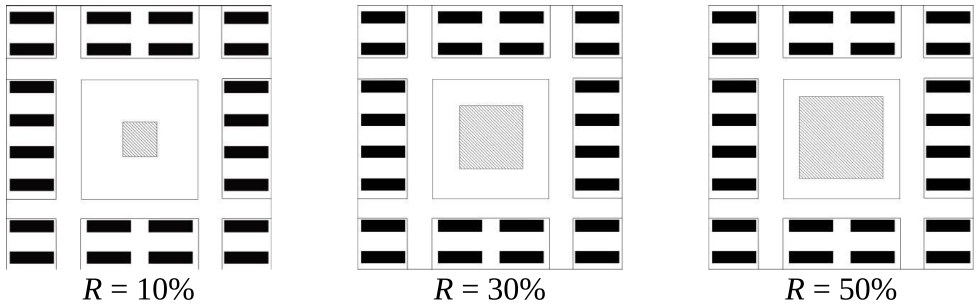


Figure 2. Different water body scale.

Water shape is also an important factor in waterscape design. The compact water body has a large water surface and plays a role as a focal point in the space. When the shape is relatively dispersed, the waterscape is generally directional, and can divide the square space. By comparing the length and area of the shape, the most compact geometry is a circle or a square, so they are usually used as the basis to measure the complexity of the shape of the patch. This paper uses squares as the benchmark for quantitative indicators of form.

$$S = \frac{0.25\mathrm{P}}{\sqrt{\mathrm{A}_w}} \tag{2}$$

Where S is the water body shape index, P is the circumference of the water body and A_w is the area of the water body. When the shape of the water body is square, the value of S is 1. The more complex or narrow the shape, the greater the value of S.

Figure 3 presents four cases with the same area and different S values for the water bodies. From left to right, the shape of the water body with the same area becomes much narrower from the squarest shape, and the value of S increases.

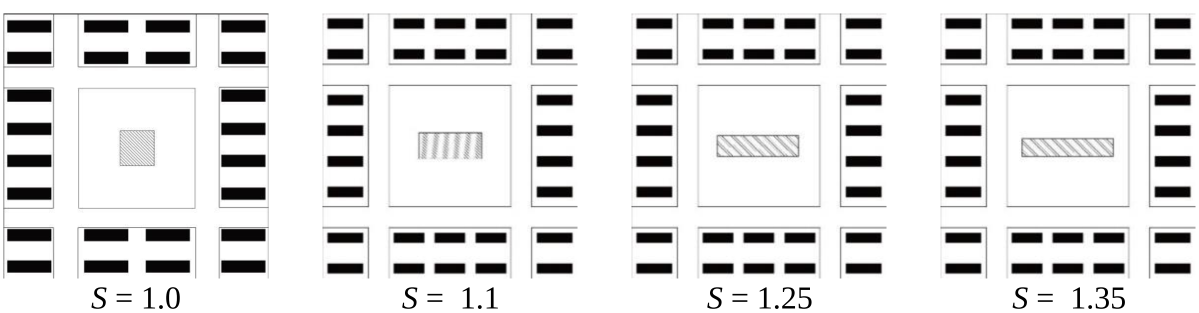


Figure 3. Different water body shape.

Based on Figure 3 and Figure 4, we have a total of 6 urban square models with different sizes and shapes of water bodies. These models will be used for microclimate simulations. Taking the case with *R=10%, S=1.0* as the control case, we will compare the differences in microclimate effects for these cases.

Microclimate Simulation with ENVI-met

We used the ENVI-met 4.0 beta version to perform microclimate simulations on all set square models. In the software, we choose the size of the model is 100m×104m×90m.The grid unit size is dx = 3 m, dy = 3 m, dz = 3 m. To eliminate the influence of the boundary on the simulation area, 30 nested grids are set to be similar to the shape of the simulation center area. Table 1 shows the relevant parameters.

Table 1. Parameter settings of ENVI-met

<table>
<tr><th></th><th colspan="2">Parameter settings</th></tr>
<tr><td rowspan="2">Location</td><td>Nanjing</td><td>E118, N32</td></tr>
<tr><td>Near ground roughness</td><td>0.01</td></tr>
<tr><td rowspan="2">Date</td><td>Summer</td><td>Jun. 22, 2016</td></tr>
<tr><td>Winter</td><td>Dec. 22, 2016</td></tr>
<tr><td rowspan="9">Meteorological parameters</td><td rowspan="2">Wind speed at 10 m height</td><td>Summer 2.4 m/s</td></tr>
<tr><td>Winter 1.1 m/s</td></tr>
<tr><td rowspan="2">Wind direction</td><td>Summer 135</td></tr>
<tr><td>Winter 45</td></tr>
<tr><td rowspan="2">Air temperature</td><td>Summer 295 K</td></tr>
<tr><td>Winter 275.15 K</td></tr>
<tr><td rowspan="2">Relative humidity at 2 m height</td><td>Summer 77%</td></tr>
<tr><td>Winter 69%</td></tr>
<tr><td>Moisture content at 2500 m height</td><td>7 g/kg</td></tr>
</table>

To provide a more comprehensive analysis of the microclimate effects of water bodies, the simulation outputs include air temperature (AT), relative humidity (RH), wind speed (WS), and predicted mean vote (PMV) for typical climate days in summer and winter. PMV is an index that predicts the average of the thermal comfort of most people (ISO 2005).

Result Analysis

Simulation results

All 6 urban square models were imported into ENVI-met. With the parameter settings described before, microclimate results of the models for a typical day in summer and winter were simulated. Here, we show the simulation results of 1.5 m height at 12:00 as a typical value of microclimate effects. Figure 4 shows the simulated results for a square with different water body area and shape in the summer. From left to right are air temperature, relative humidity, wind speed, and PMV. Similarly, Figure 5 shows the simulated results of the square in the winter.

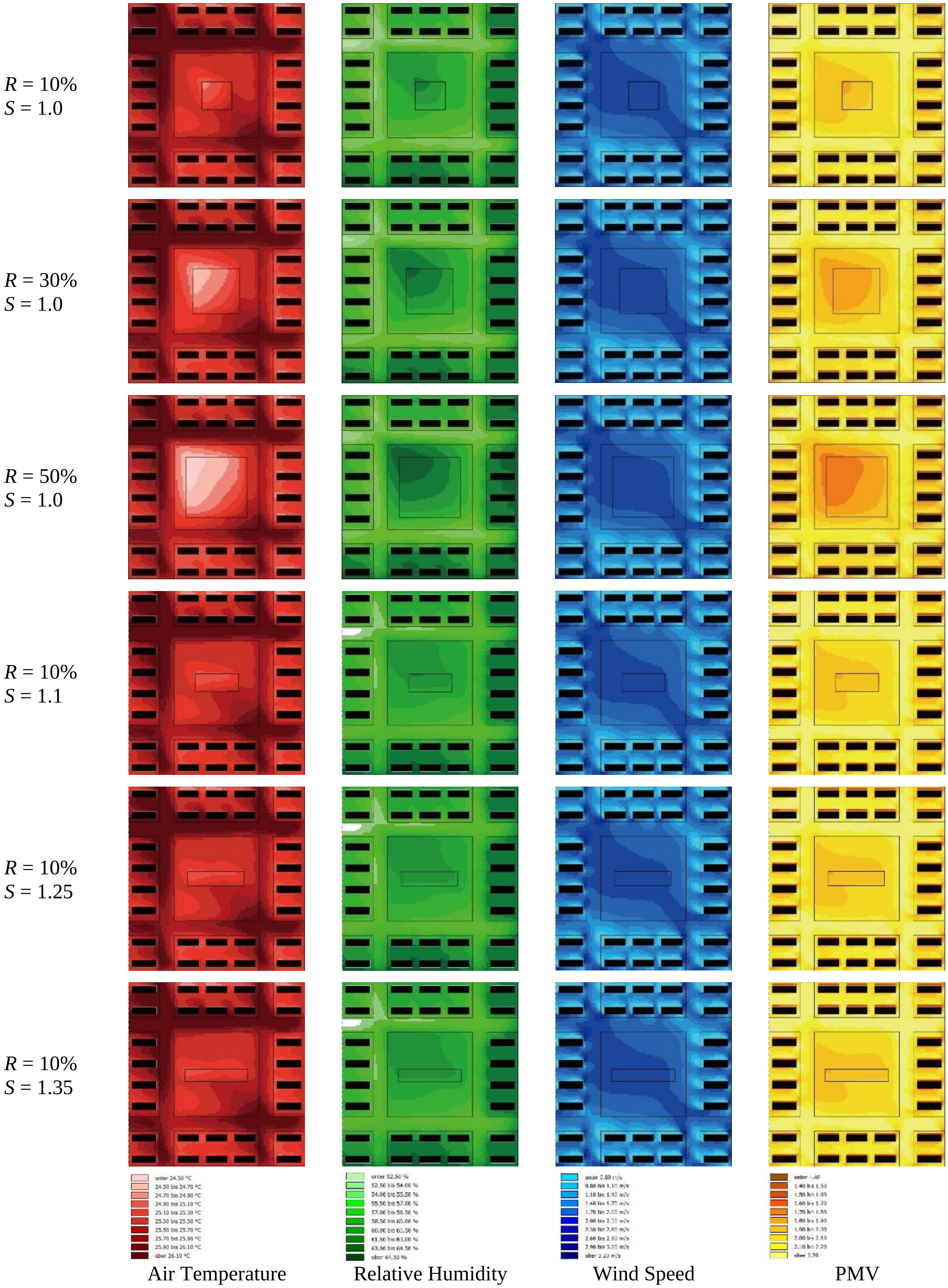


Figure 4. Simulated results in the summer.

R = 10%
S = 1.0

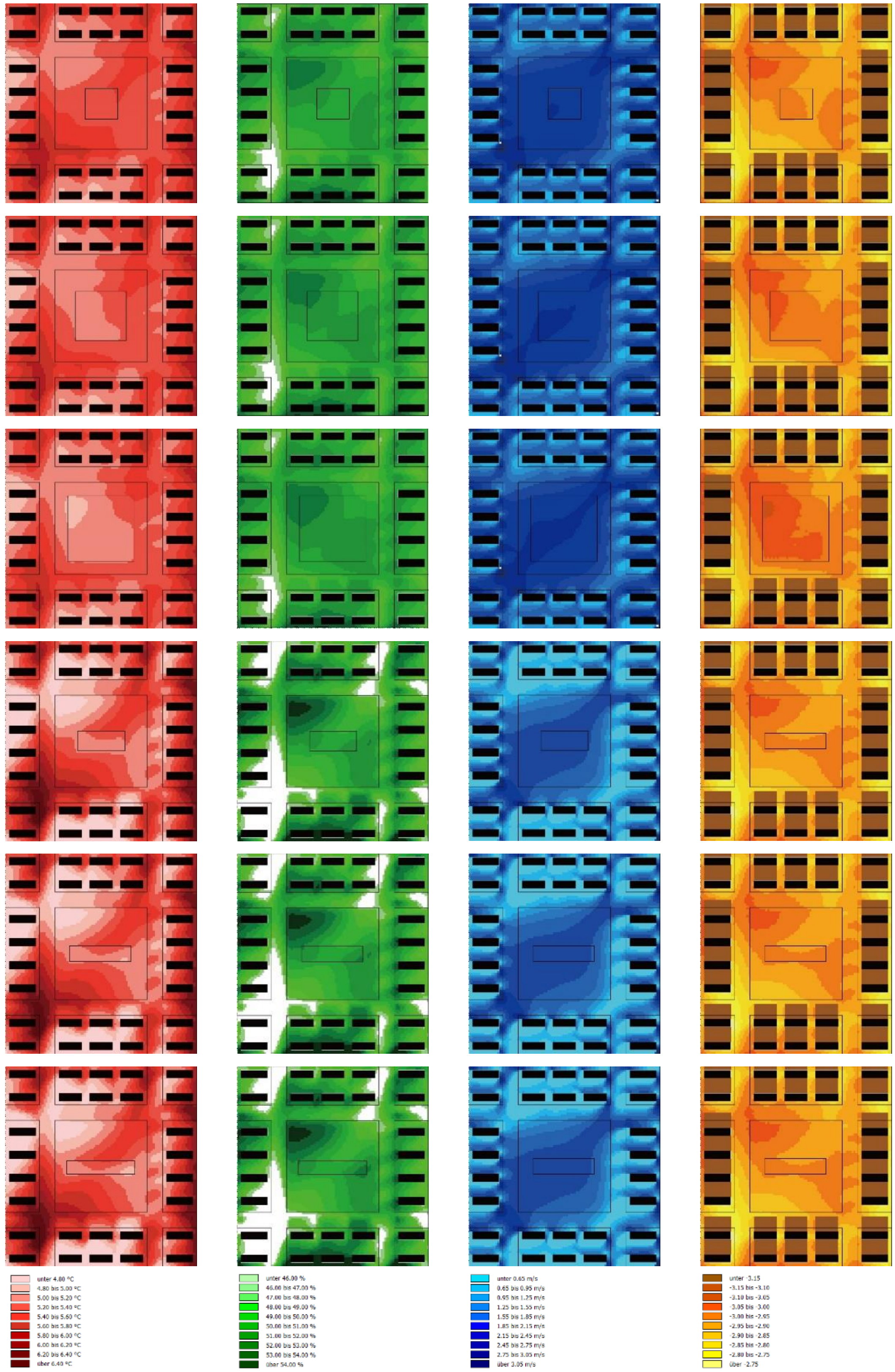
R = 30%
S = 1.0

R = 50%
S = 1.0

R = 10%
S = 1.1

R = 10%
S = 1.25

R = 10%
S = 1.35



Air Temperature | Relative Humidity | Wind Speed | PMV

Figure 5. Simulated results in the winter.

It can be seen in the figures that the water body scale has a greater influence on the microclimate effect. Especially in the summer, with the increase in the water body scale, the low temperature zone and the high humidity zone are obviously enlarged, and both appear in the downwind direction of the water body. In addition, there is a significant improvement in the thermal comfort of the human body, and an area similar to the wind shadow area is formed. This shows that the influence of water body on the downwind area is much larger than that of other areas. However, even in the downwind area, the range of influence of the water body is still limited. Furthermore, for different water body shapes, the figures do not present an obvious difference.

Statistics of the microclimate effect of water bodies

Table 2 presents the average value of the different microclimate effects of all 6 models in summer and winter. Based on the simulation results, the impact on the microclimate effect is very weak, both in terms of water scale and water shape. In all 6 models, the difference between the maximum and minimum values of the average air temperature is 0.42 degrees in summer and only 0.16 degrees in winter. The difference in relative humidity is 0.0157 in summer and only 0.0036 in winter. The difference in wind speed is 0.017 m/s in summer and 0.021 m/s in winter. The difference in PMV is 0.14 in summer and 0.044 in winter. In comparison, the influence of water body scale difference on all microclimate effects is much greater, and the influence of water body difference in summer is greater than that in winter.

Table 2. Average value of microclimate effects of different models in summer and winter

Cases	Summer				Winter			
	AT (℃)	RH	WS (m/s)	PMV	AT (℃)	RH	WS (m/s)	PMV
R = 10% S = 1.0	25.44	59.13%	1.946	2.027	5.32	57.84%	2.127	-2.946
R = 30% S = 1.0	25.24	59.88%	1.954	1.961	5.25	58.01%	2.137	-2.967
R = 50% S = 1.0	25.03	60.67%	1.963	1.889	5.17	58.19%	2.147	-2.989
R = 10% S = 1.1	25.44	59.11%	1.946	2.029	5.33	57.84%	2.127	-2.945
R = 10% S = 1.25	25.44	59.12%	1.946	2.028	5.33	57.84%	2.127	-2.945
R = 10% S = 1.35	25.45	59.10%	1.946	2.029	5.33	57.83%	2.126	-2.945

For air temperature, both in summer and winter, the increase in water body scale has a significant cooling effect (Figure 6), and the impact in summer is greater than in winter. However, the change in shape of the water body has little effect on the average air temperature of the square.

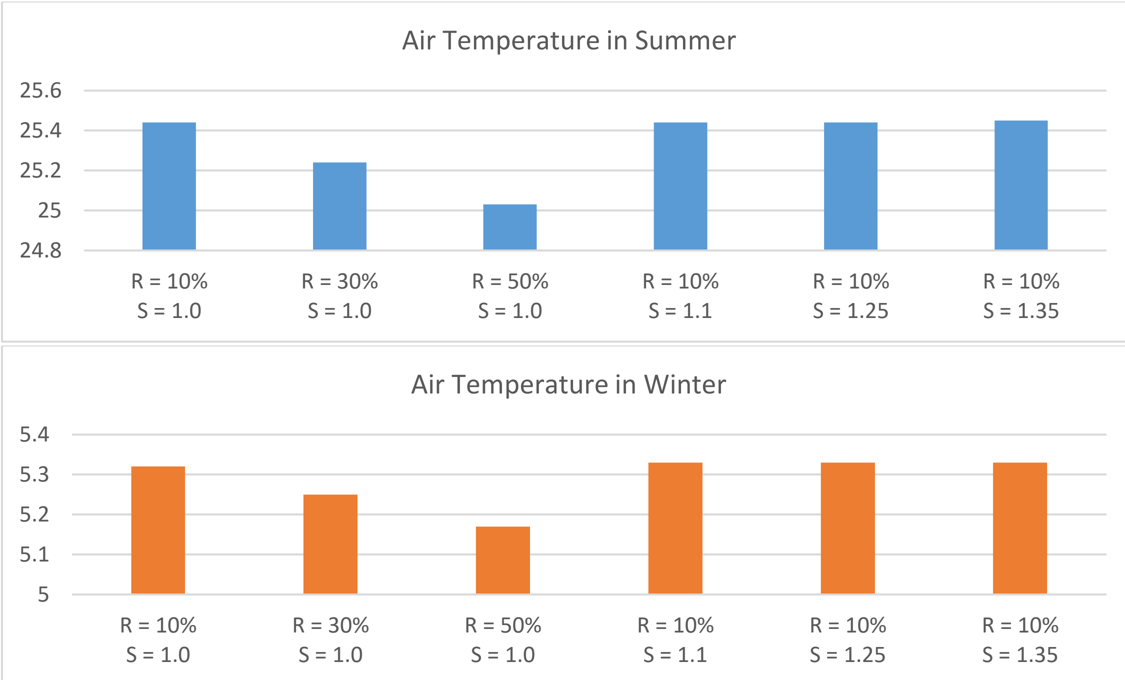


Figure 6. Comparison of air temperature of the models in summer and winter.

For relative humidity, the increase in water body scale has a significant humidification effect (Figure 7). The impact of these in summer is much greater than in winter. Similar to the air temperature, the change in shape of the water body has little effect on the average relative humidity of the square.

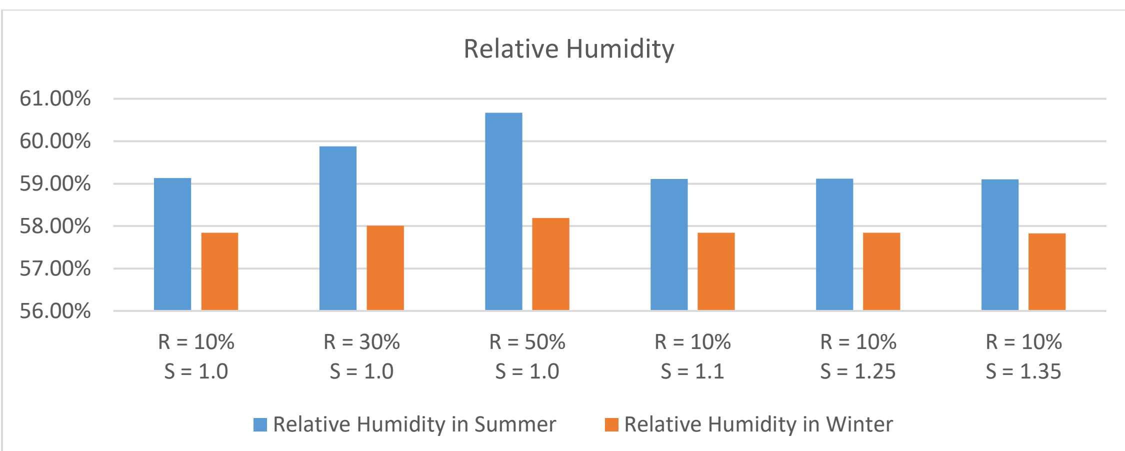


Figure 7. Comparison of relative humidity of the models in summer and winter.

For wind speed, whether in summer or winter, water body scale or shape, the impact on wind speed is minimal (Figure 8). This is because there is no vertical occlusion on the surface of the water.

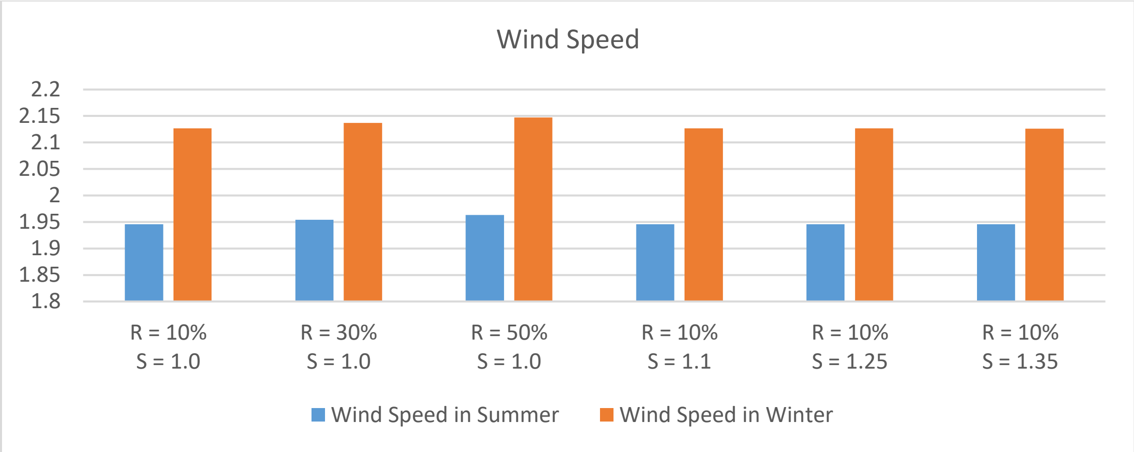


Figure 8. Comparison of wind speed of the models in summer and winter.

For PMV, in summer, an increase in water body scale will improve it, while in winter, an increase in water body scale will worsen it (Figure 9). Similarly, the change in the shape of the water body has little effect on the average PMV value of the square.

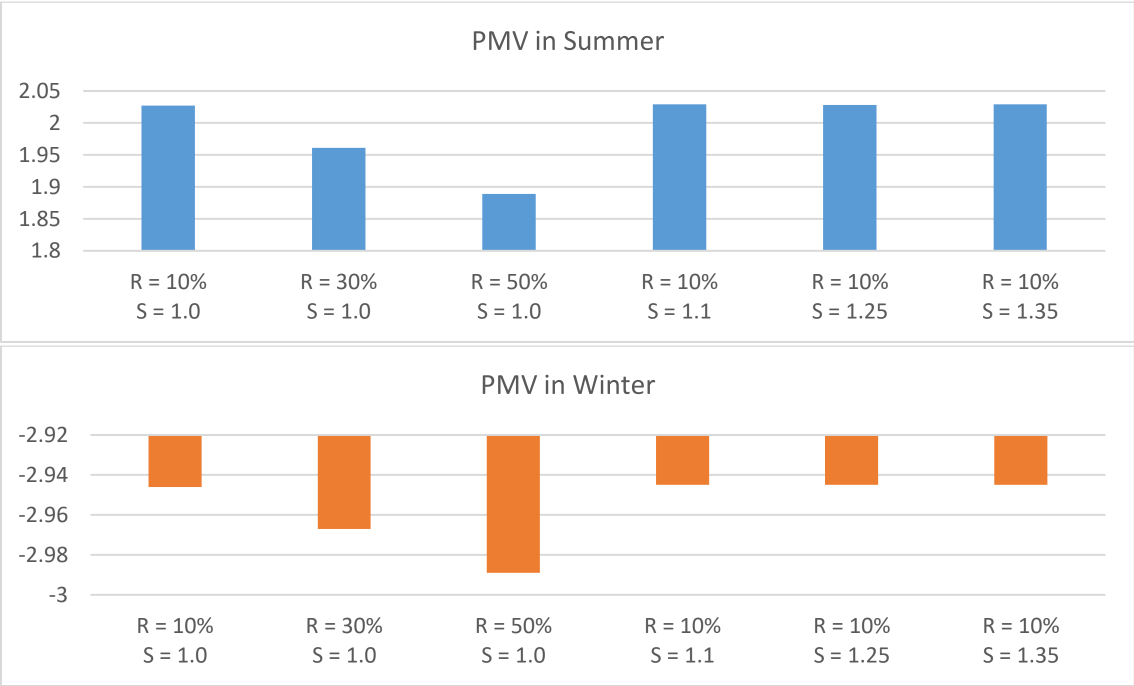


Figure 9. Comparison of PMV of the models in summer and winter.

Conclusion

Based on a survey of a large number of urban squares in Nanjing, China, this paper proposed a prototype square, including area, shape, surrounding roads and buildings. At the same time, the paper quantified the water body form with the scale and shape, and it constructed 6 basic urban square models for microclimate research. Using the ENVI-met software, we obtained microclimate simulation results for all models in summer and winter, and the data collected included air temperature, relative humidity, wind speed, and PMV.

Through the analysis of simulation results and data statistics, we believe that there is a direct correlation between water form and microclimate effect. Among the factors analyzed, the water body scale has the greatest impact on the microclimate effect. With the increase in water scale, the low temperature zone and the high humidity zone are enlarged, and the PMV is changed. The change in shape of the water has little effect on the microclimate. In addition, the influence of water body differences in summer is greater than it is in winter.

The paper's discussion of the form of the water body is limited to scale and shape, and the position and dispersion of water distribution are also important parameters of water form. We will continue to explore these two parameters further in a follow-up study.

Acknowledgments

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