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Optimization Design of Open Space Based on Microclimate and Behavior in China

Zhiming Guo[1], Tsuyoshi Setoguchi[1], Norihiro Watanabe[1] and Ke Huo[2]

1. Faculty of Engineering, Graduate School of Engineering, Hokkaido University, Sapporo 060-8628, Japan;

2. JangHo Architecture College, Northeastern University, Shenyang 110-169, China

Abstract: Traditionally, microclimate, behavior and space design are characterized by a separation among climatologists, behavior researchers and designers. It is also unrealizable to apply the research results to the space design because of the gap created by the interdisciplinarity. In addition, although the relationships among space form, urban microclimate and people are intuitively understood, there are still not reasonable predictions on how a space affects the microclimate, and how the microclimate and space will affect people's sensation and behavior. By recording the microclimate and people's responses, this paper discusses the relationship between people's sensation and microclimate as well as people's behavior and open space in a busy downtown pedestrian street during hot summer. The research finds that shade plays a crucial role in outdoor comfort. All of the other objectively comfortable and acceptable microclimates differ significantly different shade situation. Simultaneously, space contradiction can be considered an essential factor for spatial utilization. This paper also provides proposal on canyon open space design based on this case study.

Key words: Activities, outdoor comfort, urban design, street canyon, northern city.

1. Introduction

As the urbanization continues, the urban forms are constantly changing due to city construction, which change the microclimate significantly. Bonan [1], Hart and Sailor [2], and Stone and Norman [3] have discussed the influence of the urban heat island effects on microclimates based on land use, urban density and urban structures. De Schiller and Evans [4], Evans and De Schiller [5] and Eliasson [6], have discussed the significance of the subtle impact of small-scale climate variations on the urban and regional scales. At the same time, a burgeoning number of studies have examined on the relationship between outdoor thermal comfort and outdoor activities from the perspectives of meteorology and behavioristic [7-14]. There have also been some demonstrations of the influence of microclimate on people's sensation from the view point of architectural design and landscape design [15-17]. Without addressing the microclimate, many studies have been conducted regarding different aspects of public open space and behavior [18-24]. Givoni [25] has discussed the relationships among building, design and the climate and introduced the design principles for different climate regions including the cold region. There are not so many details which were offered for outdoor thermal comfort and design.

Open spaces that accommodate the daily social activities of both pedestrians and stationary people play an important role in cities. The goals of open space design are gradually evolving toward attracting more people to stay outside door and enhancing the spatial utilization [26-29]. Street canyons can be considered one of the main types of urban open space. The term "street canyon" refers to narrow street with buildings running continuously along both sides [30]. The urban canyon is an important and basic part of urban climatology and urban design [31-33]. The urban canyon can be classified into three types based on the aspect ratio (W/H means width/height): regular canyon

Corresponding author: ZhimingGuo, Ph.D. candidate, research fields: urban and regional research. E-mail: burningrain1988@eis.hokudai.ac.jp.

(an aspect ratio of approximately 1), avenue canyon (aspect ratio < 0.5) and deep canyon (an aspect ratio of approximately 2) [34]. In most cases, the commercial zones are planned in a central area, densely populated and convenient traffic area. These properties lead to its crucial status in the city. For field surveys, researching the commercial area always has more obvious applications and value [35].

For the open space design, microclimate and people's sensation and behavior in an urban open space have great references. However, research has seldom combined these viewpoints. Erell et al. [36] have discussed design and planning approaches for urban microclimates and presented two case studies at the street scale. From the viewpoint of microclimate, Erell has provided architects and urban designers a new perspective on the interaction between microclimate and each of the elements of urban landscape. However, people's behavior which can be realized as an objective standard of comfortable environment is not mentioned so much.

Using people's sensation and behavior as the standards to evaluate open space, this paper discusses the relationship between people's sensation and microclimate as well as between people's behavior and open space through a case study in a city central area in northern China. This study was discussed as follows:

(1) By analyzing the relationship between the different microclimates and people's sensations in urban canyon space in hot summer, comfortable microclimate levels and their change rules were estimated;

(2) From the viewpoint of microclimate and spatial behavior, the comfortable open space forms were discussed, and then proposals of regional open space optimizationdesign are proposed for the future sustainable urban construction or reconstruction.

2. Methods

2.1 Field Survey

The study case is a typical urban open space located in central area of Shenyang, China (41°48′01.11″ N, 123°27′49.33″ E, ASL (above sea level) = 55 m). This place can be realised as one of the commercial centres with multitudinous visitors every day. In this case, the pedestrian street canyon is between two large scale mixed-used buildings with shopping malls, subway station, super market, hotels and high rise apartments (Fig. 1). The densely-populated area can provide more samples and more accurate reference for the research. In the center of the research area, during the survey time, there was a temporary exhibition zone which leads to a more complicated behavior situation. This study excluded the exhibition zone from the behavior research.

Based on the history daily maximum temperature data from July to September in the period of 2009-2014 from the National Meteorological Information Center in China (Fig. 2) [37], this study selected July 28th to August 9th, 2015 (12 days) as the summer high temperature survey period.

2.2Microclimate and Sensation

As Fig. 3 shows, depending on the space situation, 11 types of spaces were considered. The positions, space styles, aspect ratios and facilities were used to define these spaces. Then, 15 measurement points were chosen according to the space types and the spatial distributions. These 15 points were separated in 3 groups with 5 points in each group. Microclimate data of each point were collected every 15 minutes during the daytime, including: air temperature (T_a), air velocity (V), relative humidity (RH), globe temperature (T_g) and shade situations. Table 1 shows the measurement factors of micrometeorological parameters.

Mean radiant temperature (T_{mrt}) is defined as the "uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in actual non-uniform enclosure" [38]. It is put forward based on the exchange of radiant energy between two objects by emitting and adsorbing heat. In this study, the T_{mrt} is

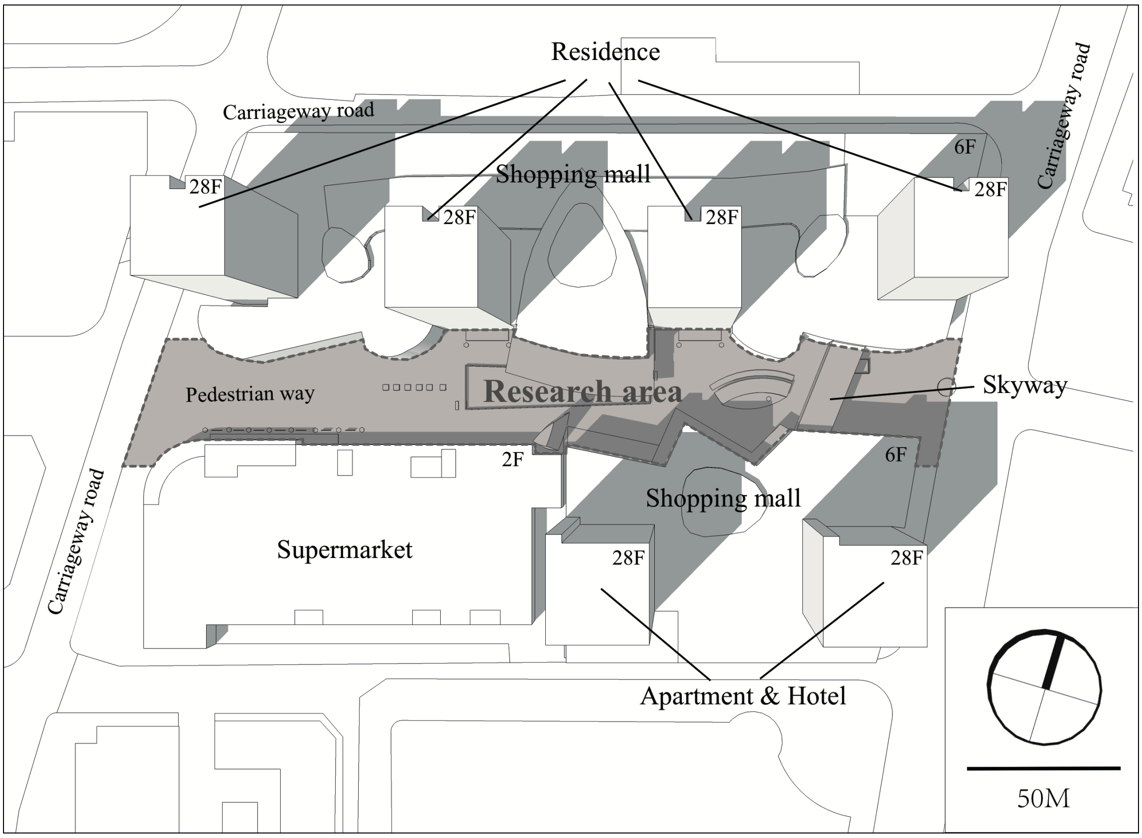


Fig. 1 Research area.

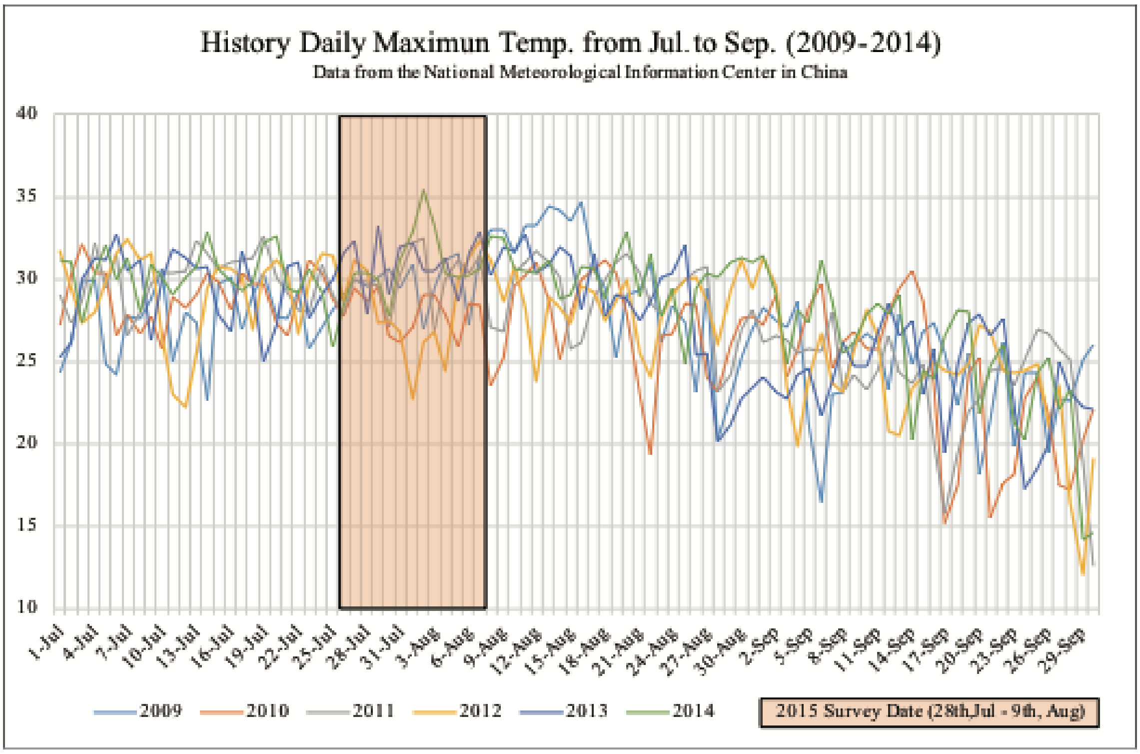


Fig. 2 History of daily maximum air temperature from July to September, 2009-2014.

Note: Weather station No.: 54342 coordinates: 41°44 N, 123°31 E, ASL = 49 m.

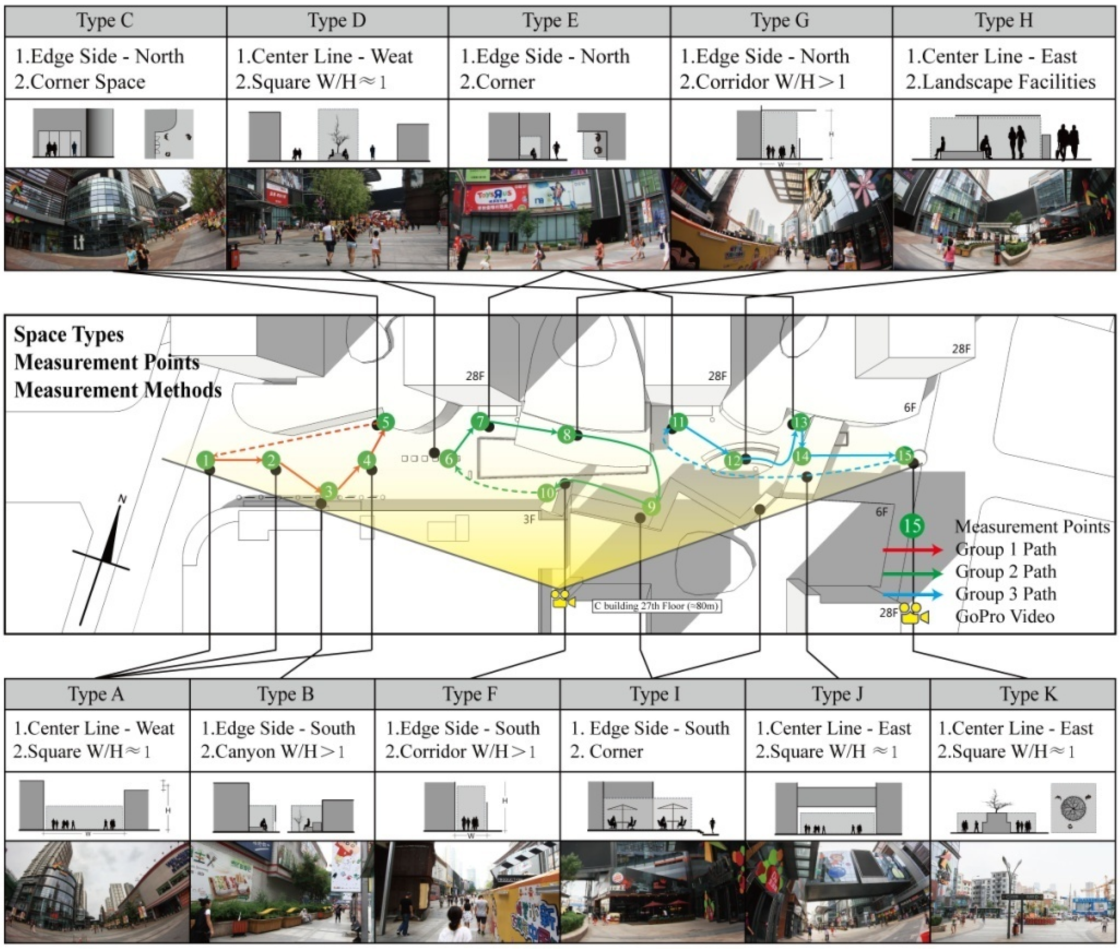


Fig. 3 Space types, position information and measurement methods.

Table 1 Measurement factors of microclimate parameters

Parameter	Accuracy	Resolution	Range	Setting
V	3%	0.1 m/s	0.6 to 40.0 m/s	Measurement Point No. 1 to No. 15, 1.5 m in height
T_a	0.5 °C	0.1 °C	-29.0 to 70.0 °C	
RH	3.0%	0.1%	5% to 95%	
T_g	0.6 °C	0.1 °C	0-80 °C	

estimated by the globe temperature method. Depending on the previous study, there are relatively small differences between the globe temperature methods and other complicated methods [39]. T_{mrt} is calculated based on the following equation [37]:

$$T_{mrt} = \left[\left(T_g + 273\right)^4 + \frac{1.10\times10^8 V^{0.6}}{\varepsilon D^{0.4}} \left(T_g - T_a\right) \right]^{\frac{1}{4}} - 273 \quad (1)$$

where, T_{mrt} is the mean radiant temperature (°C), T_g is the globe temperature (°C), T_a is air temperature, V is air velocity (m/s), D is globe diameter (m) (in this study D = 0.075 m), ε is emissivity (0.95 for black-colored globe).

Combined with the real-time microclimate data, a 7-point CSV (comfort sensation vote) [40] for the subjective responses of preferred change was used by the subjects to record their comfort levels. According to this scale, -3 is very uncomfortable, 0 is neutral and 3 is very comfortable; any recording higher than -1 is defined as acceptable. For the 15 points, during the survey days, in total, more than 2,400 groups of effective data were recorded. In the high position (27th floor in a high-rise building, approximately 80-m tall), a Hi-Q video camera was used to record people's behavior during the survey. Panorama images were taken every 30 min at measurement points 1, 3, 10 and 14 simultaneously to record the positions of people.

Depending on the solar incident angle based on the CSWD (Chinese Standard Weather Data) [41] and the Chinese standard for Assessment Parameters of Sunlight on Building (GB/T50947- 2014) [42], this study used software to simulate the shadows in August 1st before sunset as a reference of the general shade situation.

2.3 Open Space and Behavior

This study analyzed the spatial behavior in August 1st and 4th as a comparison of sunny and overcast days. By analyzing the panorama images and the time lapse videos, the spatial behavior was analyzed including position maps and pedestrian routes. In the position maps, the study drew down people's position for every 30 min from 9:30 to 20:00, including the pedestrians and stationaries, and integrated them into one picture and counted the quantity of users, including the pedestrians and stationary people. In the pedestrian routes, the study used the time lapse video to draw down the moving path of the pedestrians with the same quantity (210 pedestrians in each day) during the lunch time (12:00-12:30) which can be realized as the busiest period during one day to analyze the different behaviors between different microclimate situations.

3. Results

3.1 Sensation with Microclimate

Over 2,400 groups of microclimate data and corresponding CSV were collected. The measured temperature range during the survey was 24.4-35.9 °C. The air velocity between 0-7.1 m/s was recorded. The measured relative humidity range was between 36% and 100%. The weather situations, e.g., clear days, overcast days, thunderstorm and partly cloudy days, were included during the survey.

Table 2 shows the correlation analysis between CSV and shade, T_{mrt}, T_a, T_g, V and RH by using the software IBM SPSS Statistics (Version 20.0.0). Bivariate correlation algorithms were used to analyze the correlation [43]. The Pearson correlation is a measure of the linear correlation between the two variables X and Y, giving a value between +1 and −1 inclusive, where 1 is total positive correlation, 0 is no correlation, and -1 is total negative correlation.

As the Pearson correlation shows, all the correlations are significant at the 0.01 level. That is, all the measured microclimate factors will affect the CSV, respectively. Among them, shade has the highest correlation (r = -0.464) with CSV, followed by RH (r = 0.449), T_a (r = -0.421). Consequently, the shade situation was the main factor to affect people's satisfaction of environment.

Measured air temperature and calculated mean radiant temperature (T_{mrt}) on clear and overcast days

Table 2 Correlations between CSV and measured microclimates (n = 2,489).

	CSV	Shade	T_a	V	RH	T_g
CSV	1					
Shade	-0.464**	1				
T_a	-0.421**	0.288**	1			
V	0.222**	-0.080**	-0.157**	1		
RH	0.449**	-0.287**	-0.685**	0.165**	1	
T_g	-0.354**	0.312**	0.415**	-0.078**	-0.438**	1

** Correlation is significant at the 0.01 level (2-tailed).

CSV—comfort sensation votes, T_a—air temperature, T_{mrt}—mean temperature radiant, V—air velocity, RH—relative humidity, T_g—globe temperature.

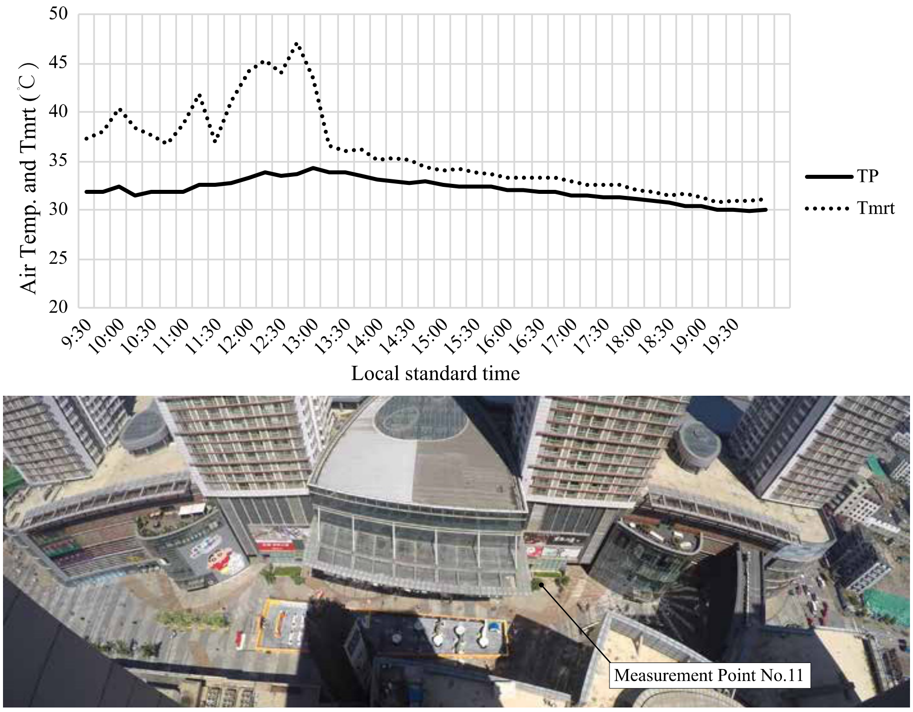


Fig. 4 Measured air temperature and calculated mean radiant temperature on a clear day (August 5th, 2015) and the photograph at 10:30.

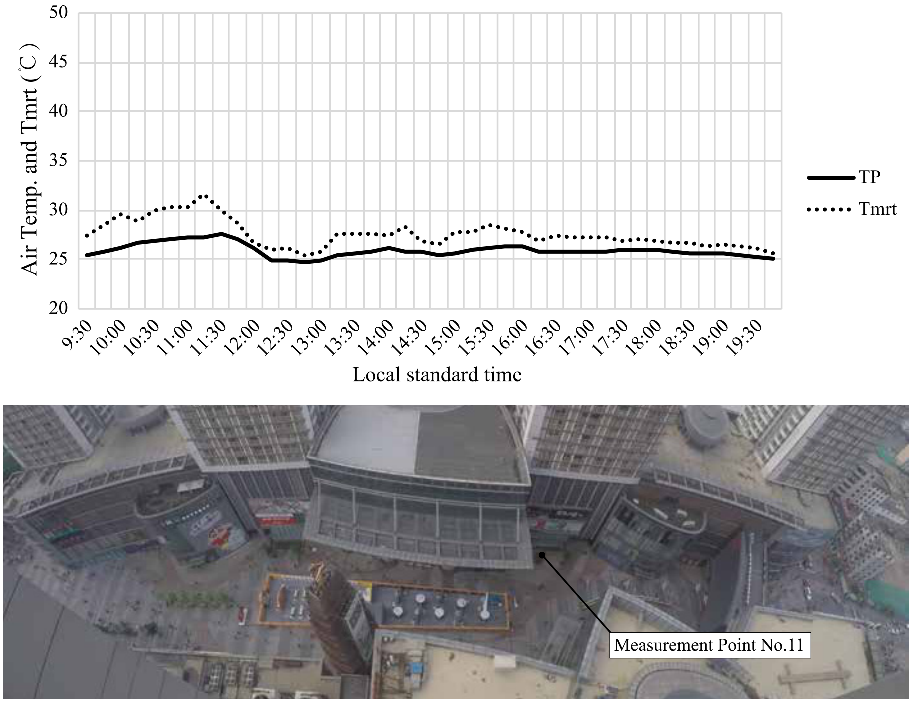


Fig. 5 Measured air temperature and calculated mean radiant temperature on an overcast day (August 6th, 2015) and the photograph at 10:30.

were shown in Figs. 4 and 5. The measurement point for this comparison was set on Point No. 11 where it can get sunlight before afternoon on clear day and change slightly on air velocity during whole day.

The difference of air temperature and mean radiant temperature between clear day and overcast day was shown. The difference of mean air temperature between two days was 6.13 °C. During the clear day, higher temperature was recorded. The effect of shade on the magnitude of T_{mrt} was also clearly shown. Depending on Figs. 4 and 5, on the clear day, when the measurement point was exposed in sunlight before 13:00, T_{mrt} is significantly higher than the air temperature. When the building shade fell over the measurement point, slightly higher T_{mrt} than air temperature was recorded. The same result was also found in overcast day.

It should note that, however, the results in specific days may be subject to several errors. Nevertheless, combining with the above correlation results, and several previous studies, shade will play an important role on people's comfort [44-47]. It can be considered as higher priority to separate the other factors on analyzingthe outdoor situation.

The general relationships between CSV, and mean microclimate in each period in different shade situations were analyzed. As shown in Fig. 6, the following results were obtained: First, the CSV tendency of "not in the shade" is significantly lower than "in the shade". When subjects are in the shade, they are comfortable with a CSV of 0 to 1 all day. However, when they are out of the shade, all the measured CSV belong to the uncomfortable level. Second, the temperature and humidity indicate the general variation of the CSV. Higher temperature and lower humidity in the noon decrease the CSV. Third, the ruler guides of Nos. 1-8 indicated the extremums of CSV. It can be found that, instantaneous variations of the CSV are related to the wind speed. Higher wind speed made the CSV lower, lower wind speed made the CSV higher.

By using microclimate data and mean CSV (n = 2,520), the detailed relationships between CSV and microclimate in the shade are plotted in Fig. 7. In

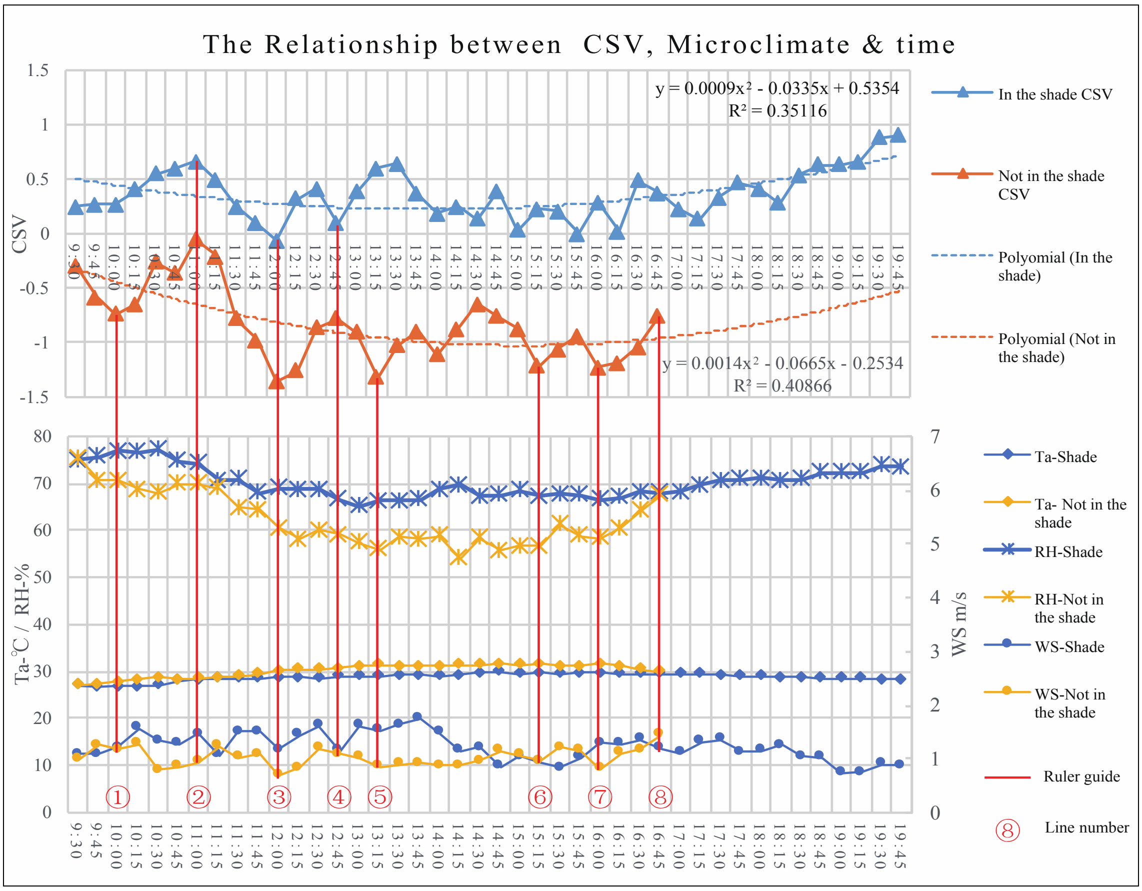
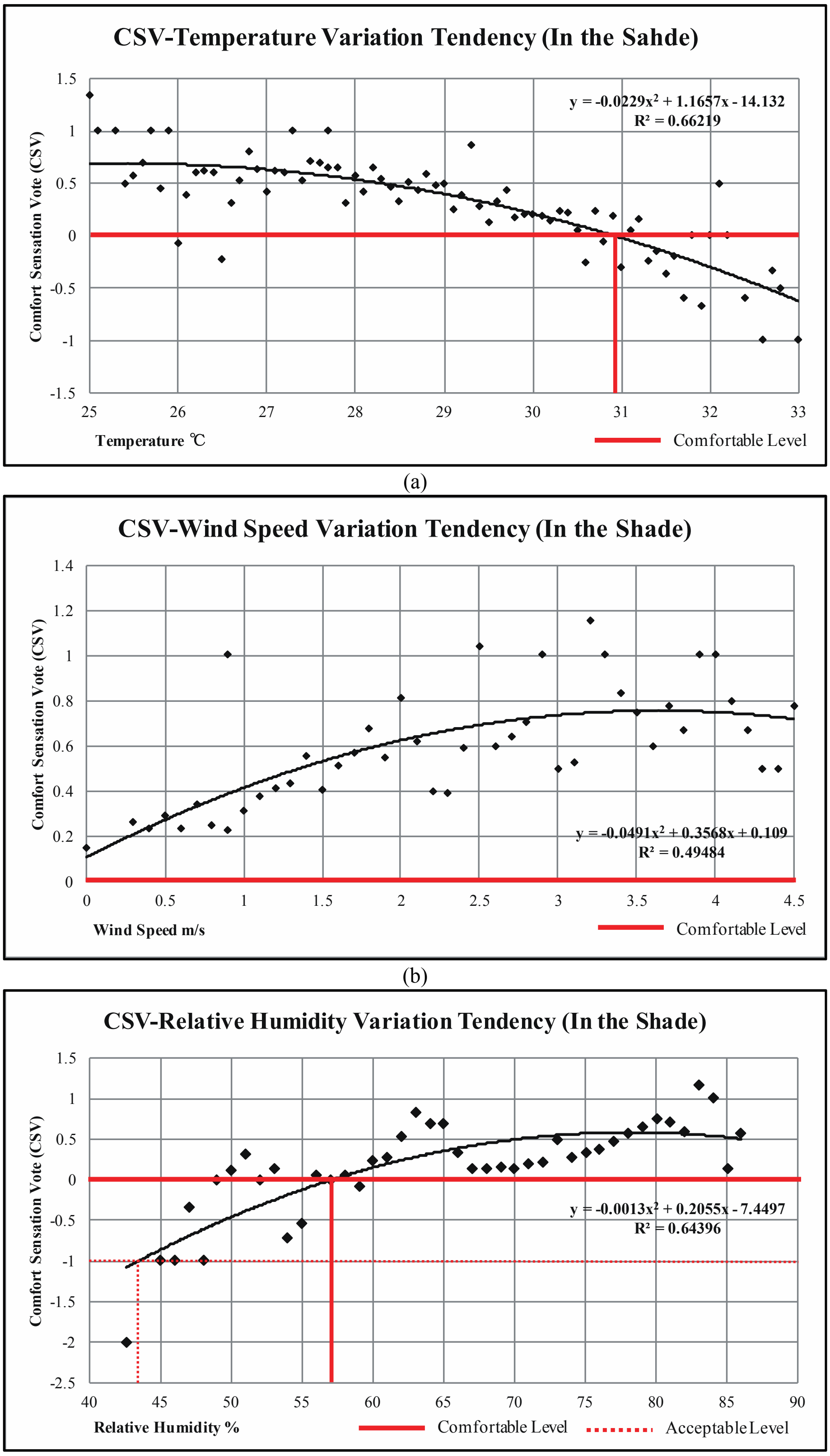


Fig. 6 The general relationships between CSV and mean microclimate in each period in different shade situations (n = 2,520).



(c)

Fig. 7 CSV: (a) mean T_a (in the shade); (b) mean V (in the shade); (c) mean RH variation tendency (in the shade).

the shade, CSV will decrease with increasing temperature and belong to the comfortable range of -1 to 1. As the equations binomial curve fitting shows, a temperature of ≤ 30.9 °C can be considered comfortable. The CSV increases with increasing wind speed, and all the measured wind speeds belong to the comfortable level of 0 to 1 in the shade. However, when the wind speed is in the range of 0~3.5 m/s, the comfortable level increases. When the wind speed is over 3.5 m/s, the comfortable level decreases. The CSV increases with increasing relative humidity. A relative humidity that is higher than 57% can be considered comfortable. However, when it is lower than 43%, it is not considered acceptable.

Meanwhile, the detailed relationships between CSV and microclimate out of the shade are plotted in Fig. 8. It can be found that all the measured elements cannot meet the comfort requirements except for the relative humidity. Parts of each microclimate element belong to the acceptable range (CSV > -1). The CSV increases with increasing wind speed and relative humidity and will decrease with the increasing temperature. When the temperature is lower than 30.7 °C, the comfortable level in acceptable. When the temperature is higher than 27 °C, the comfortable level decreases significantly. When the wind speed is faster than 1.25 m/s, the comfort is within the acceptable range. When the wind speed is close to 3 m/s, it is possible to obtain a comfortable level. For relative humidity, the situation can be considered comfortable when the relative humidity is higher than 78%. When the relative humidity is lower than 64.5%, the comfort is in an unacceptable range.

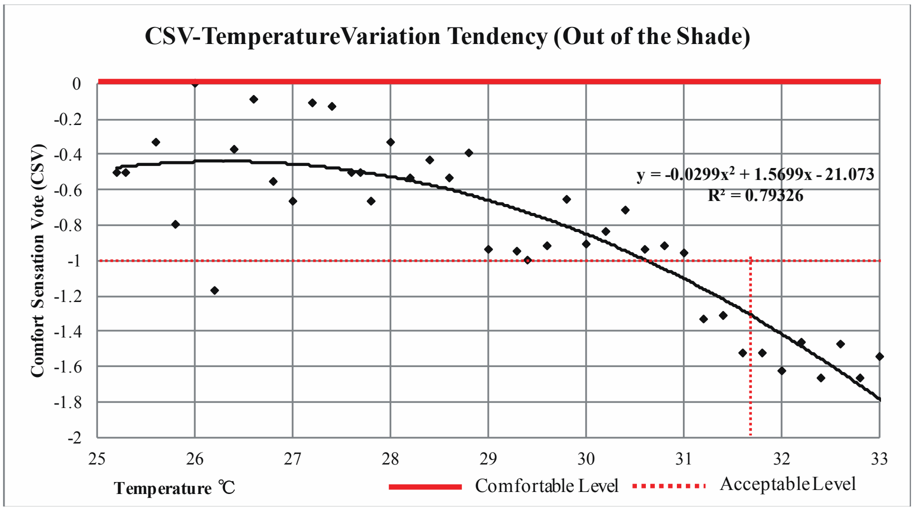
Additionally, the shade period before sunset at each measurement point is analyzed. Different colors represent different sunshine duration. Depending on the spatial arrangement, the positions are separated into the center line and edges. The center line is composed of east and west parts, in which the edge sides are composed of south and north parts. As shown in Fig. 9, the east side has more shade than the west side and the edge side has more shade than the center. Meanwhile, the south edge side has more shade than the north side. The corner (Nos. 7, 9, 11 and 13) and the under-roof locations (Nos. 8 and 12) also can provide more shade than the wide-open spaces such as Nos. 1, 2, 4, 6 and 15.

Based on the above results, the mean microclimate including T_a, WS and RH in different positions are also analyzed with the mean CSV. There are only slight differences in the mean temperature and humidity among the 15 points. However, the wind speeds vary for each point. As Fig. 10 shows, the center line has higher wind speed than the edges, especially at location Nos. 4, 6, 12 and 14, which are in the broad square and do not have any obstacles in the prevailing wind direction (east-west). Nevertheless, both ends of the center line (Nos. 1 and 15) have lower wind speeds than the other locations. Hence, uneven space edges, especially on the south side, can provide relatively favorable shade situations without higher wind speeds. The center line position can provide a favorable wind environment, but the broad square cannot provide a long period of shade. As shown by the mean CSV in each point, the comfortable position sequence from high to low is as follows: east center, south edge, north edge and west center. That is, the differences in shade and wind speed significantly influence the comfortable level.

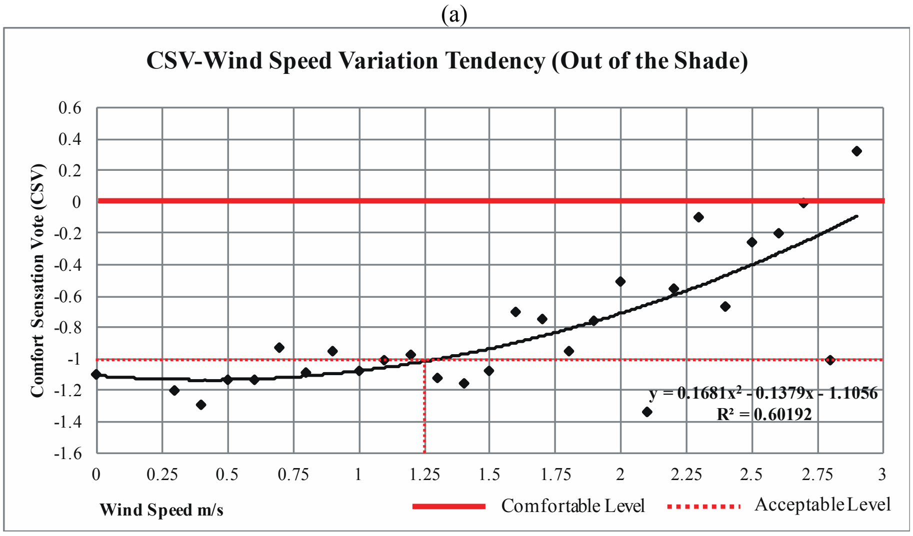
3.2 Behavior in Open Space

By using the panoramas, the position maps were analyzed in August 1st and 4th as a comparison of sunny and overcast day. As Fig. 11 shows, the study drew down the people's position for every 30 mins from 9:30 to 20:00, including the pedestrians and stationaries, and integrated them into one figure and counted the quantity of users (Fig. 12) by the separation of shade situation and behavior.

As shown in Fig. 11, on an overcast day, outdoor space can attract more people than clear day. On a clear day, the east side with long periods of shade, abundant



(a)



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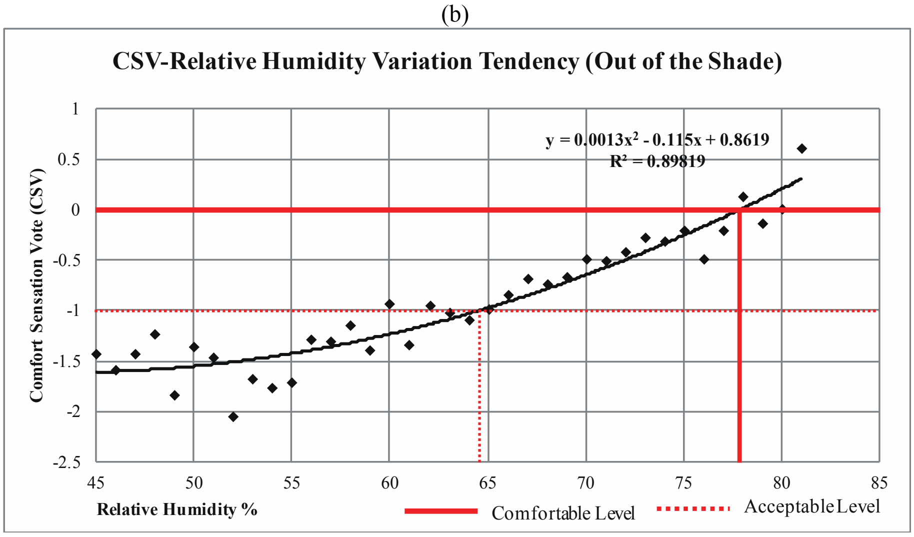


(c)

Fig. 8 CSV: (a) mean T_a (out of the shade); (b) mean V (out of the shade); (c) mean RH variation tendency (out of the shade).

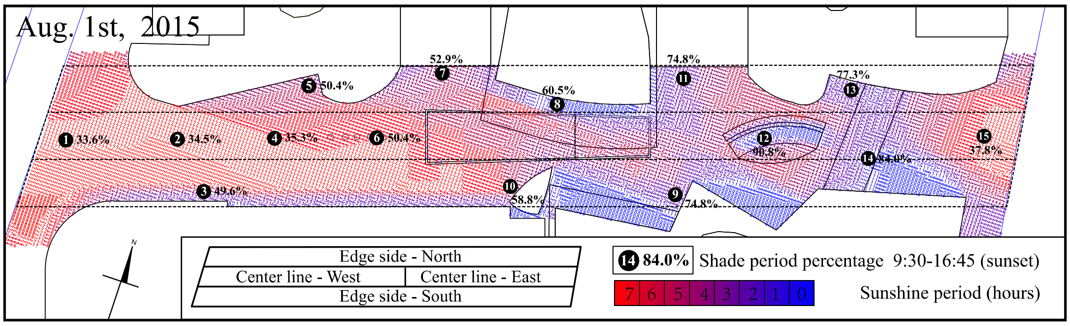
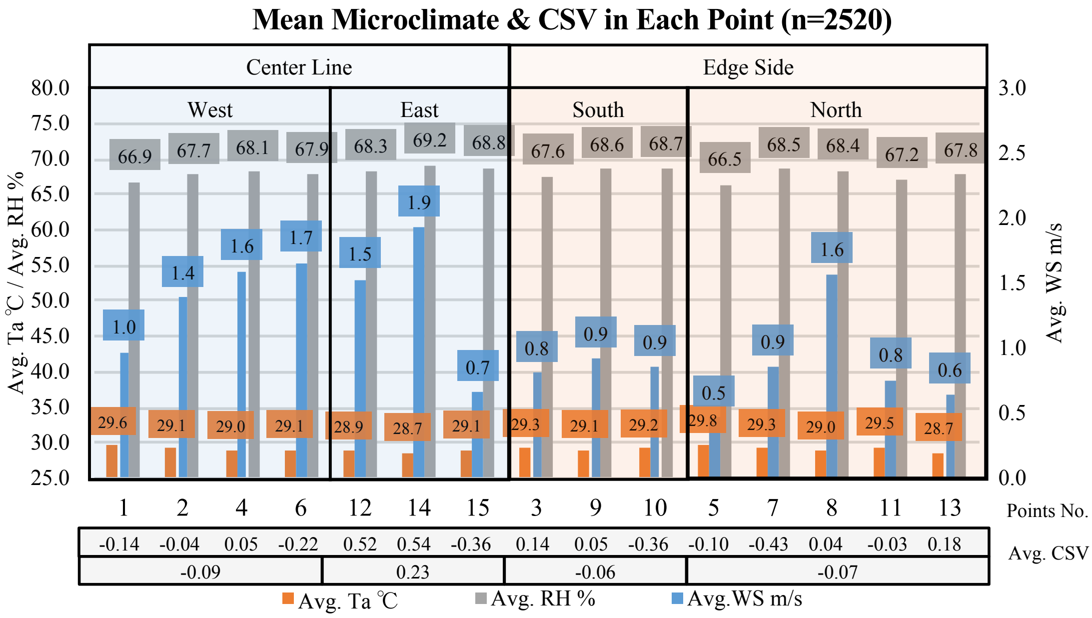


Fig. 9 Shadow situation before sunset.



Points No.	1	2	4	6	12	14	15	3	9	10	5	7	8	11	13
Avg. Ta ℃	29.6	29.1	29.0	29.1	28.9	28.7	29.1	29.3	29.1	29.2	29.8	29.3	29.0	29.5	28.7
Avg. RH %	66.9	67.7	68.1	67.9	68.3	69.2	68.8	67.6	68.6	68.7	66.5	68.5	68.4	67.2	67.8
Avg. WS m/s	1.0	1.4	1.6	1.7	1.5	1.9	0.7	0.8	0.9	0.9	0.5	0.9	1.6	0.8	0.6
Avg. CSV	-0.14	-0.04	0.05	-0.22	0.52	0.54	-0.36	0.14	0.05	-0.36	-0.10	-0.43	0.04	-0.03	0.18
Avg. CSV (group)	-0.09				0.23			-0.06			-0.07				

Fig. 10 Mean microclimate factors in each point with CSV.

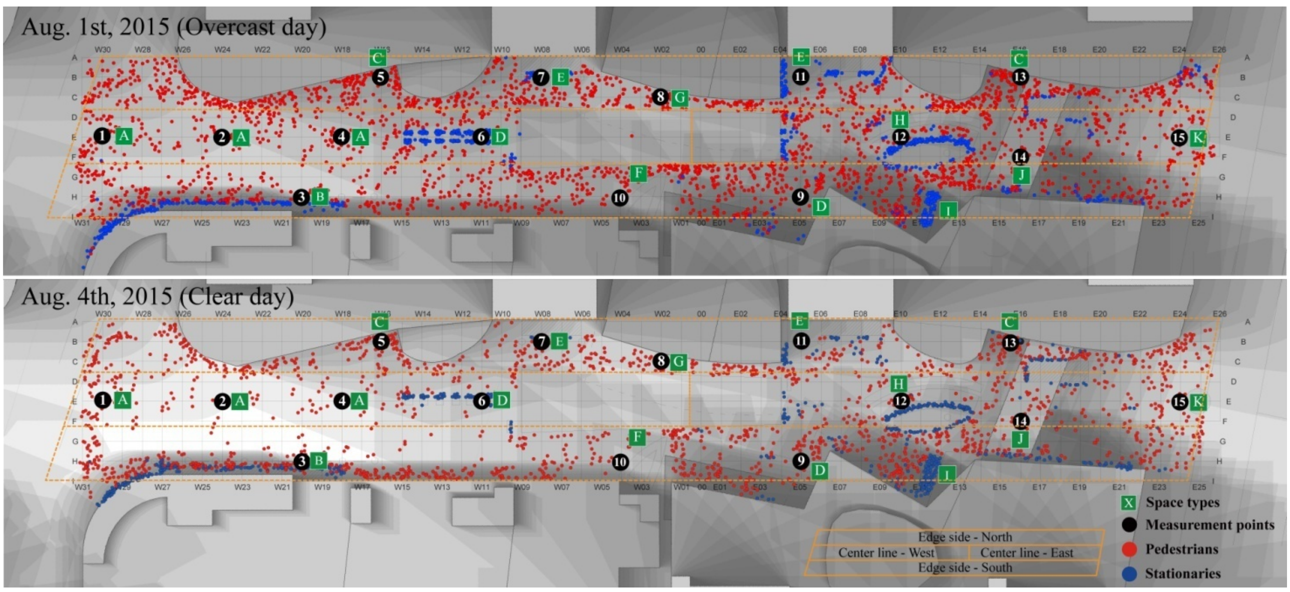


Fig. 11 The position relationship between clear day (August 1st) and overcast day (August 4th).

seats and other facilities (Nos. 9/Space Types I, 11/E, 12/H, 13/C and 14/J) can gather more people than the west side (Nos. 1, 2 and 4). The south side has more shade and can therefore gather more people than the north side, especially the area on the south side with seats or places to stay (e.g., Nos. 3/B and 9/I).

In these 2 days, the square type space A (Nos. 1, 2 and 4) and their south side square show low usage rates. People neither prefer to stay in or pass by the too-wide space that lacks any structures norspends long periods here. The activities tend to be irregular and fill the area on anovercast day. Many stationary people will choose to stay near the building edges (e.g., No. 3/B). Also, most of the pedestrians prefer to pass by the edge space (e.g., Nos. 5/C, 9/D, I and 13/C). The building corner (e.g., No. 9/I and 11/E) with seats and shade is suitable for long time stays. It can provide independent and quiet spaces that do not interfere with pedestrians. Space Type I can also provide a height difference to isolate two different types of space. Also, the under-roof space, such as Space Type H can provide thick shade all day. With the facilities such as seats, shrubs and fences, it is suitable for long stays.

Fig. 12 shows the number of people in these 2 days. The total number in overcast day before sunset is more than clear day in each measured time except 9:30. Both on an overcast day and a clear day, there are about 20%-30% of stationary people in the outdoor space. Before sunset, especially in overcast day, the number of the stationaries remained stable. During the survey, the static space is always full of people. To some degree, it can reflect the capacity of the static space. On a clear day, before sunset, about 60% of the people will stay in the shade. Combine with the former result, shade is an important element on the outdoor comfort.

The study also picked up the lunch time during these 2 days to draw down the pedestrian routes. The characteristicsof pedestrians were analyzed with the same quantity between different microclimate situations. As shown in Fig. 13, when the number of analyzed people is equal, the general routes are in the east-west direction (left-right direction). All the

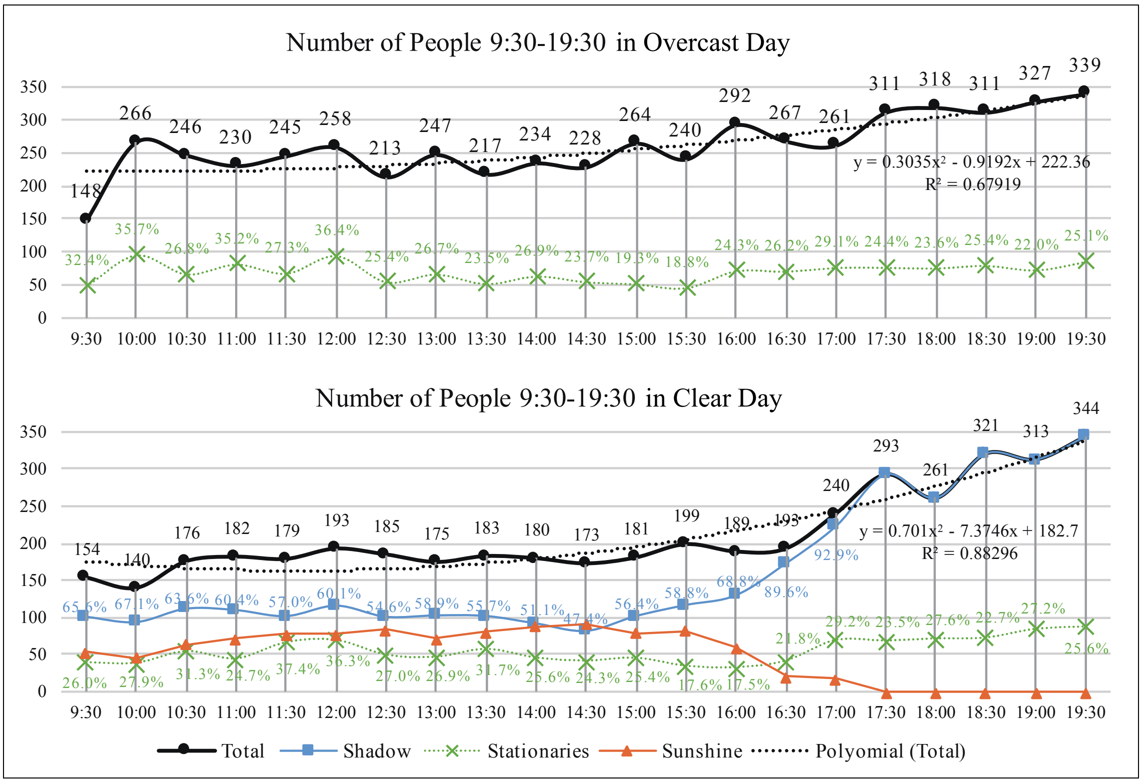


Fig. 12 Number of people comparison between clear day (August 1st) and overcast day (August 4th).

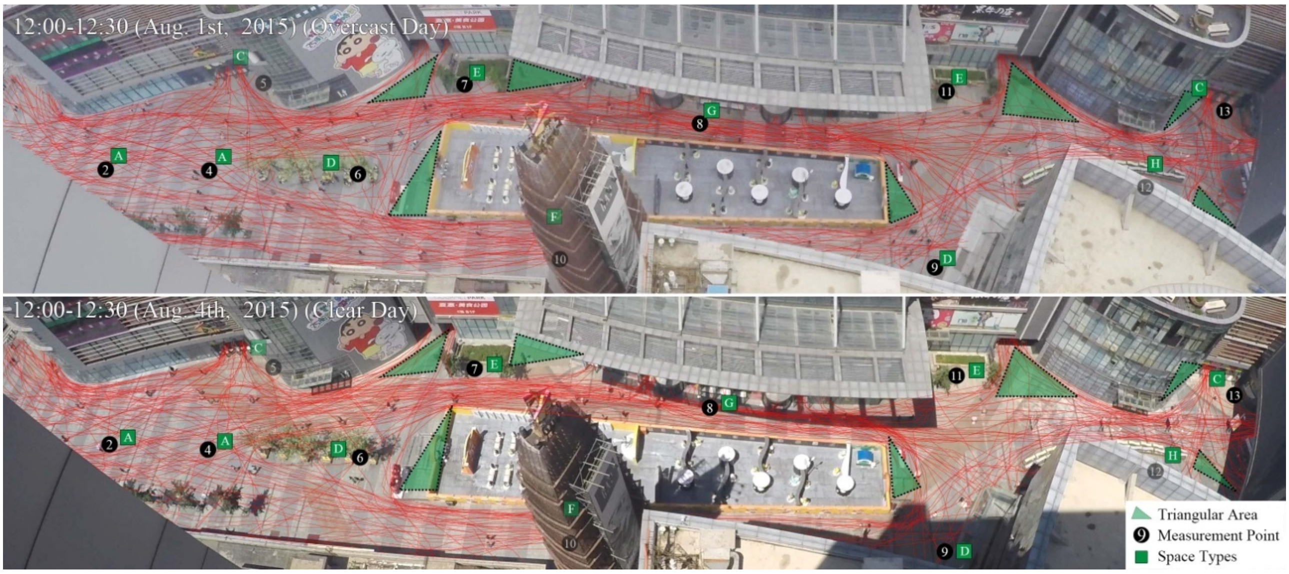


Fig. 13 Pedestrian routes comparison between clear day (August 1st) and overcast day (August 4th).

pedestrian routes are curved with almost no straight lines. In both cases, the pedestrian routes tend to be thicker at the edge of the buildings and the narrow spaces (Space Types F and G). When the space becomes wider, the routes tend to be laxer. Narrow canyon type spaces and the cross-flow are the space disadvantages for pedestrians. Pedestrians can choose any path in this case. It will create interferences between the pedestrians and stationary people, such as Space Types D (No. 6) and E (No. 7), because there are almost no boundaries or separations between the static space and dynamic space. However, a static place that has sufficient space in front does not cause as much interference with pedestrians, such as Space Types I and E (No. 11). Also, some triangular blank areas are formed by angular space edges and curved pedestrian routes. Both pedestrians and stationary people do not tend to choose this type of space that has the potential for interference.

4. Conclusion

This research focused on the relationship among open space design, people and microclimate. Through a field survey in a commercial open space, the study analyzed the microclimate elements that have a remarkable influence on behavior and feeling during the hottest summer in a northern China. The analyses and results led to the following conclusions:

4.1 Microclimate and Sensation

(1) In summer, shade plays a crucial role in the outdoor comfort. All the other objectively comfortable and acceptable microclimates show significant differences in different shade situations;

(2) In the shade, the comfortable temperature is ≤ 30.9 °C, the comfortable relative humidity is ≥ 57% and all the measured wind speeds (0-4.5 m/s) belong to the comfortable level. Meanwhile, a higher wind speed can increase the comfortable sensation. When the wind speed is in the range of 0~3.5 m/s, the comfortable level can expand. When the wind speed is over 3.5 m/s, the comfortable level decreases. When not in the shade, no measured temperature or wind speed can satisfy the comfortable requirements. The comfortable relative humidity is ≤ 78%. The acceptable temperature is ≤ 30.7 °C, humidity is ≥ 64.5%, and the wind speed is ≥ 1.25 m/s;

(3) In this canyon space, the mean temperature and humidity at each point are approximately the same; however, the wind speeds and shade that change CSV are distributed unevenly. The shade period sequence from long to short is as follows: south edge, north edge,

east center and west center. The wind speed in the center line is higher than on the edges. The CSV position sequence from high to low is as follows: east center, south edge, north edge and west center. That is, the difference in shade and wind speed significantly influences the comfort level.

4.2 Open Space and Behavior

(1) Shade can encourage more people to use the space;

(2) People prefer to choose the place with higher wind speed, and thick shade for either staying or passing by;

(3) Seats, space edges, corner spaces, under the roof spaces, the space with abundant landscape facilities and the spaces with height differences are popular for stationary people, especially when the location can meet the comfortable conditions. Too-wide square spaces, narrow aisles and spaces without abundant facilities are unpopular;

(4) Curved pedestrian routes without boundaries and angular static spaces create interference between pedestrians and stationary people and create triangular blank areas that are wastes of traffic space.

5. Discussion and Design Optimization

For this case, shade is an essential requirement for the people who want to be active outside and should be given priority in design. Additionally, using the naturally longer shade on the east side, more static space can be designed. At the west side, more landscape structures should be designed to enlarge the shading area and increase the comfort level here.

Dynamic spaces and static spaces should be clearly separated to avoid the space use conflicts to improve space utilization. Avoiding too-wide spaces without facilities and too narrow space and creating more comfortable static spaces with enough facilities can improve the quality of a space. Reducing rectilinear spaces and making more rounded spaces without angular edges can provide a flowing space for pedestrians and can also decrease the interference between dynamic and static spaces.

For stationary people, corner spaces, building edges and the center line area with higher wind speed should be thoughtfully considered to attract more people to stay for longer times. Creating landscape structures that are open to the direction of the prevailing summer wind and providing shade, seats and spatial separations among the above-mentioned places are necessary for a high-quality static space.

Based on the above results and conclusions, designing a canyon open space as a sandwich structure can be realized as a solution for the comfortable sensation and spatial utilization. As Fig. 14 shows, the static space should be arranged in the middle side and at the edge of the buildings. The traffic space is placed between these two static spaces. This design can not only improve the space utilization and decrease interference between stationary people and pedestrians but also offer possibilities for creating a favorable microclimate environment. Because the wind environment

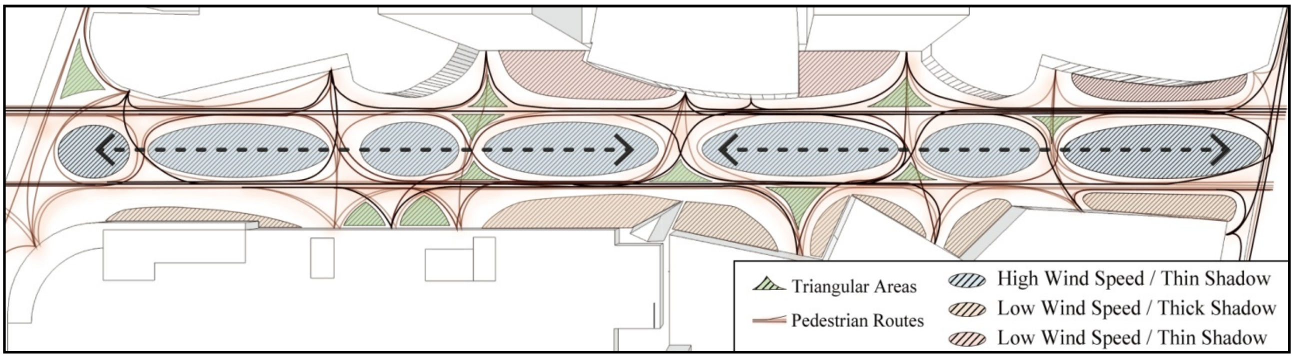


Fig. 14 Optimization design of canyon open space.

in the middle is better than that on the edges, designing the shading structures and humidifiers that are open to the wind direction can create a favorable environment based on the above-mentioned principle of a comfortable microclimate.

To create a suitable and high-quality open space that is comfortable for both pedestrians and stationary people, the following proposals should be considered:

(1) At the beginning of the open space design, understand the general microclimate situation and the comfortable threshold in the hottest day. Among all the microclimate elements, shade plays a crucial role and should be considered first. Roofs and plants, etc., that can provide thick enough shade. Based on theseparameters, different design methods will be separated by different microclimate situation (Fig. 15).

(2) Curved pedestrian routes should be planned with rounded space edges to enhance spatial utilization. The triangular blank area formed by a curved route and an angular boundary can be used for some functional landscape structures such as streamline leading or symbols (Fig. 16);

(3) Avoid too-wide square spaces without any facilities and too-narrow spaces. Provide abundant street facilities which can offer shade, resting areas and spatial separations at suitable places without spatial contradiction. By controlling the width of the traffic space with streamline leading structures, traffic efficiency can be improved by design. Additionally, depending on the shade distribution, setting landscape structures and plants that are open to the prevailing wind direction is necessary to ensure the spatial utilization (Fig. 17);

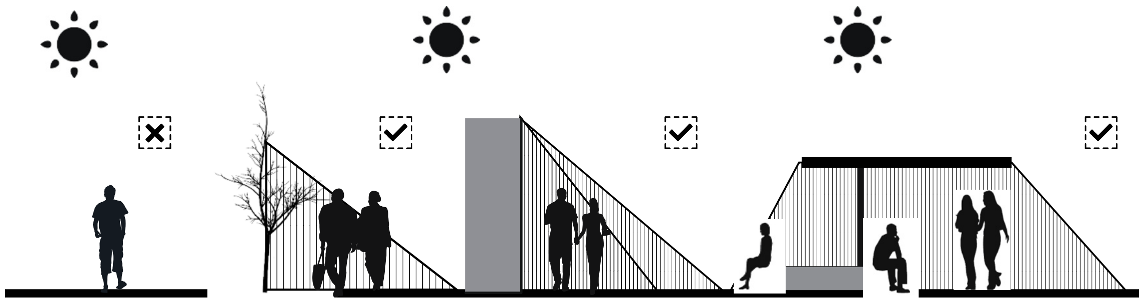


Fig. 15 Comfortable microclimate creation.

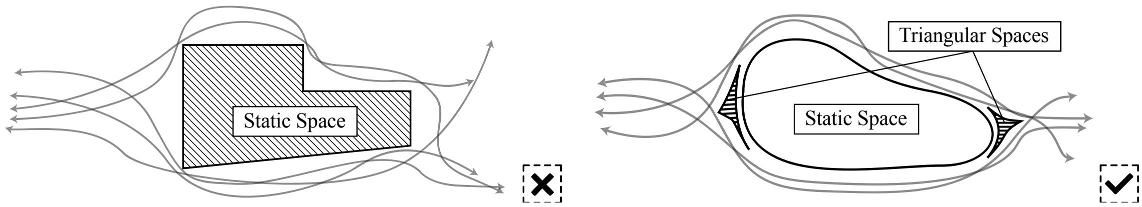


Fig. 16 Flowing route and curve space.

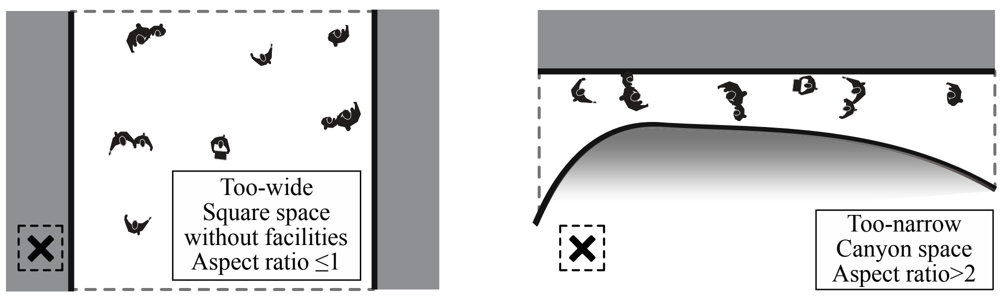


Fig. 17 Spatial scale.

Fig. 18 Space interference.

(4) By creating independent static spaces in the centerline area, edge side area and corners, interference between pedestrians and stationary people can be avoided. Meanwhile, spatial separations, such as fences, billboards, shrubs, height differences, are necessary in areas that could create conflicts. Providing sufficient functional facilities and structures are required to create an attractive place (Fig. 18).

6. Future Study

The microclimate in a northern city varies greatly between summer and winter. In Shenyang, China, the average annual temperature ranges from 1981 to 2010 is 35.8 °C [48]. Based on the summer study, the future research will focus on the cold winter situation. By analyzing both summer and winter, comprehensive and integrated proposals will be provided for the urban design of open space for northern cities with large temperature differences.

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