sustainability

MDPI

Article

A Study of the Pedestrianized Zone for Tourists: Urban Design Effects on Humans' Thermal Comfort in Fo Shan City, Southern China

Xuan Ma [1,2,*], Hiroatsu Fukuda [1,*], Dian Zhou [2,*] and Mengying Wang [3]

1 Faculty of Environmental Engineering, The University of Kitakyushu, Kitakyushu 8080135, Japan
2 School of Human Settlements and Civil Engineering, Xi'an Jiaotong University, Xi'an 710049, China
3 Graduate school of Human-Environment Studies, Kyushu University, Fukuoka 8190002, Japan; 3HE18401S@s.Kyushu-u.ac.jp
* Correspondence: mxozil@yahoo.com (X.M.); fukuda@kitakyu-u.ac.jp (H.F.); dian-z@mail.xjtu.edu.cn (D.Z.); Tel.: +81-0704-804-8803 (X.M.); +81-0803-959-3582 (H.F.); +86-1318-611-5860 (D.Z.)

Received: 28 February 2019; Accepted: 5 May 2019; Published: 15 May 2019

Abstract: Ling Nan Tian Di block is in Fo Shan city, which is in the hot-summer and warm-winter climate area of China and is a very important scenic spot. A pedestrianized zone aims to provide a commercial and recreational center for tourists. The utilization of it is determined by the outdoor microclimate, which affects not only humans' thermal sensation but also the commercial value; thus, putting forward the best time of day to visit this region in extreme summer is very necessary. Using the result of this work, tourists can choose the most comfortable time of day with the most suitable thermal conditions to visit this pedestrianized zone. To this end, we conducted field measurements and numerical simulations to analyze thermal sensation. In addition, a field questionnaire survey was utilized to evaluate the thermal comfort range for tourists. The analyzed result shows that the thermal comfort range of tourists is a physiological equivalent temperature (PET) of 22 to 28 °C and the neutral PET is 25 °C. The final thermal calendar shows that the whole commercial zone is within the comfort range after 7:00 p.m. During the daytime, except for the open space without vegetation, the whole region is in the comfort range from 8:00 a.m. to 10:00 a.m.

Keywords: pedestrianized zone; outdoor thermal comfort; questionnaire survey; measurement survey; thermal calendar

1. Introduction

1.1. Tourism and Climate

With the development of China's economy, tourism became the most important source of income and an opportunity for employment. The climatic conditions are the main factors affecting tourism [1,2]; moreover, climate can determine the touristic areas [3,4] and influence tourism demand in different places [5].

According to the research results of previous studies [6], when compared to local citizens, tourists are more sensitive to climatic conditions, and prefer places with a higher level of thermal comfort [7]. It is, thus, very necessary for us to provide essential information to help tourists schedule their traveling. An integrated evaluation of human thermal sensation and the physical beauty of the touring sites can largely improve the capability of a touristic region. Therefore, the climatic conditions of tourists' destinations is very important for planners [8].

1.2. Development of Thermal Comfort on Tourism

Mieczkowski firstly used an index called the tourism climate comfort index (TCCI) with seven different climatic factors to evaluate outdoor suitability for tourists [9]. In 1997, Mayer and Matzarakis researched heat stress at 12 meteorological stations in Germany and converted its value to a climatic map [10]. Freitas believed that the tourism climate can be assessed from thermal and aesthetic physical aspects and outlined different aspects of the tourism climate in 2003 [11]. In 2005, Yan evaluated human comfort zone in China [12]. In 2008, Matzarakis and Lin studied tourists' thermal comfort at the Sun Moon Lake in Taiwan [13], and, in 2012, in a study in Iran, researchers firstly evaluated thermal sensation using the physiological equivalent temperature (PET) and tourist climate index (TCI) over the course of one year [14]. In addition, a few studies were done on tourism of different places in Europe [15]. Aforementioned studies in different places showed that most of them were conducted in cities and countries using data provided by meteorological stations to estimate comfort range for tourists. However, no available information on tourists' thermal sensation in urban public space can be found so far.

1.3. Thermal Comfort and Urban Public Spaces

Several studies concluded that there is a strong correlation between microclimate and the utilization of the outdoor public spaces [16–18]; comfortable regions and climates can better attract tourists [19]. Commercial pedestrianized zones play a significant role in humans' lives, and they are not only symbols of cities but also an important factor increasing financial income. Humans' thermal comfort in these areas is of importance due to its influence on outdoor vitality [20], human health [19], and outdoor energy consumption of buildings [21].

Urban public space has a significant influence on the microclimate, and a person who stands in the street of a pedestrianized zone will experience two different forms of solar radiation which can influence thermal sensation (Figure 1). The first form is called short-wave radiation; this is emitted from the sun and commonly defined as sunlight. The second form is called long-wave radiation; this is emitted from outdoor terrestrial surfaces that surround the person. Additionally, a human's thermal comfort is also affected by the evaporation of the vegetation and wind velocity [22].

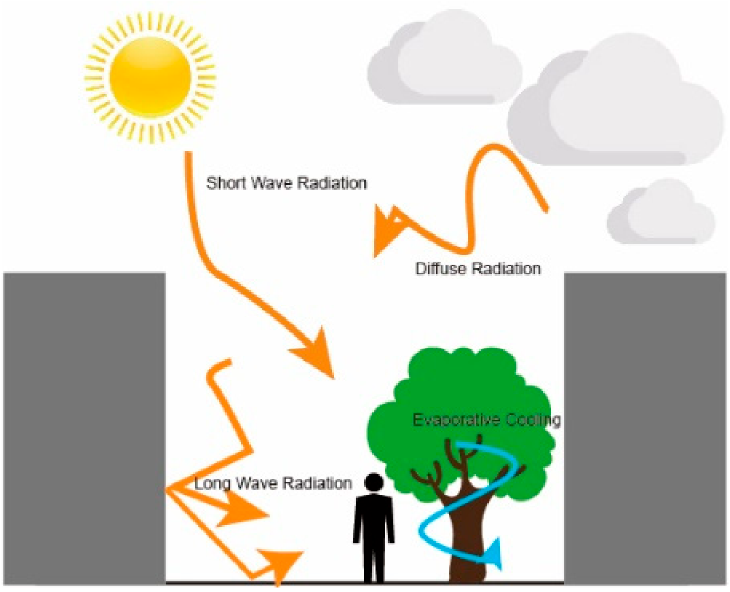


Figure 1. Outdoor energy exchange between the street and outdoor environment.

It is important for us to recognize the different factors affecting thermal comfort in summer in order to create suitable conditions [23,24]. Plans and geometry of urban space are the effective factors in creating microclimate of the public space [25]. Impeding the radiation can obviously alleviate heat stress in summer, and increasing the height-to-width ratio (H/W) and reducing the sky view factor (SVF) can improve thermal comfort effectively [26–28], where SVF is the extent of the sky observed from a point as a proportion of the total possible sky hemisphere. In addition, the street orientation also has an influence on modifying thermal comfort in subtropical regions [29]. Vegetation, including trees and grass, can modify heat stress through evapotranspiration effects [30,31]. Additionally, hardened ground can be heated by solar radiation during the daytime; thus, reducing the coverage ratio of pavement material of hardened ground can improve thermal comfort [32].

In different climatic conditions, humans will experience different thermal sensation during the daytime. Further, most previous studies focused their attention at the urban level [23,33–43], while very limited studies were conducted by analyzing thermal comfort in commercial pedestrianized zones, especially in subtropical regions. In addition, most of the previous research sites are first-tier cities [26–28]; few studies were conducted to evaluate second- and third-tier cities in China.

Climate change and weather conditions play a crucial role in humans' quality of thermal comfort and, consequently, on tourists throughout their traveling days. Despite the uncomfortable thermal conditions in the hot-summer subtropical region of Fo Shan city, high numbers of tourists still visit this city in this season [43]. Therefore, paying attention to the thermal comfort of tourists in summer is very necessary. In this study, an on-site measurement, questionnaire survey, and numerical simulation are conducted to research tourists' thermal sensation in hot summer. The final results can compare the thermal conditions of an urban pedestrianized zone, based on which tourists can choose the most comfortable time for visiting on days under heat stress and local managers can redesign this area under new suggestions.

2. Methods

2.1. The Research Site

China covers a very large territory with various climate zones. According to the national standard Thermal Design Code for Civil Building (GB50176-93) [44], five climate zones are found: hot-summer and cold-winter areas, hot-summer and warm-winter areas, cold areas, severe cold areas, and temperate areas. Fo Shan (23°02′ west (W), 113°06′ east (E)) is located in Guang Dong province (Figure 2), which is in the hot-summer and warm-winter climate area (Figure 3).

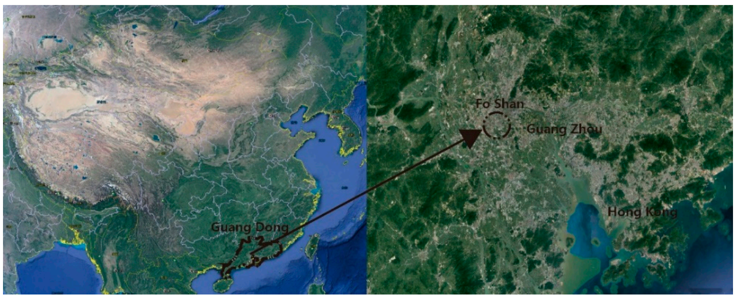


Figure 2. The location of the city of Fo Shan.

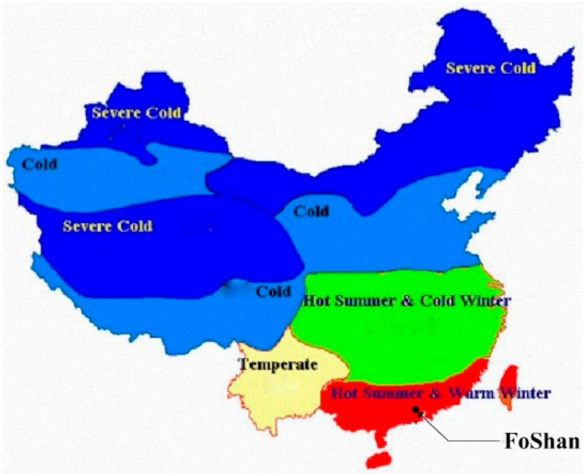


Figure 3. Climate classification of Fo Shan according to the national standard Thermal Design Code for Civil Building [44].

Alternatively, according to Köppen –Geiger's climate classification, Fo Shan city has a fully humid climate in the summer (Figure 4) [45].

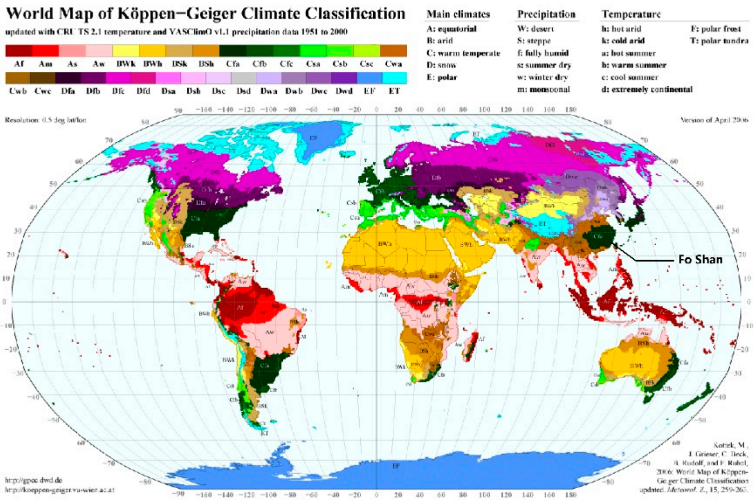


Figure 4. Climate classification of Fo Shan in Köppen–Geiger's climate classification [45].

Considering the published data from weather stations, the average annual air temperature of this city is 22.5 °C in the summer and the prevailing wind is from the southeastern direction [46]. The daily maximum air temperature in July 2016 (Figure 5) reached 37 °C [46].

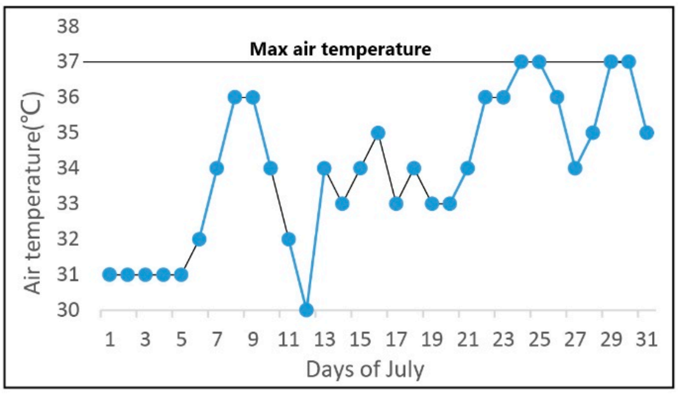


Figure 5. Daily maximum air temperature in July 2016 [46].

In this study, the Ling Nan Tian Di commercial pedestrianized zone was selected to evaluate tourists' thermal sensation. The location of this region is shown in Figure 6. This commercial zone is not only an important symbol of Fo Shan city but is also a very important place increasing local financial income [35].

Figure 6. The location of the Ling Nan Tian Di pedestrianized zone.

The whole commercial zone consists of open space and canyon space (Tables 1 and 2). In order to provide a deep understanding of the microclimate of this area, the whole commercial zone was divided into seven parts in accordance with the different spatial geometry. In the canyon space, point 1 and point 2 have the same aspect ratio (H/W) and different orientation; in addition, point 1, point 3, and point 5 have the same street orientation and different aspect ratios (H/W). Compared to other canyon points, point 6 has a different orientation and aspect ratio (H/W). In the open space, point 7 has vegetation to provide shade for tourists, but point 4 has no vegetation.

Table 1. Characteristics of the different sites of this pedestrianized zone. N, E, W, S—north, east, west, south; H/W—height-to-width ratio.

Point	Characteristic	Surface	Shade	Aspect Ratio (H/W)
1	NW-SE direction	Paving granite	√	1.25
2	N-S direction	Paving granite	-	1.25
3	NW-SE direction	Paving granite	√	1.5
4	Open space	Brick	-	0.2
5	NW-SE direction	Paving granite	√	0.5
6	NE-SW direction	Paving granite	√	1
7	Open space	Paving granite	√	0.25

In addition, the measured SVF (Sky View Factor) of different selected points was calculated by Rayman (Meteorological Institute of the University of Freiburg, Freiburg, Germany) through fisheye images; meanwhile, using Google maps (Google company, Atlanta, United States) and an on-site survey, we built a simulated model including an artificial structure and shading devices in ENVI-met (Bochum University, Bochum, Germany) to calculate the simulated SVF. A comparison between the measured and simulated SVF was used to assure the accuracy of the built model and the final simulated results (Figure 7).

Table 2. Characteristics of different selected sites.

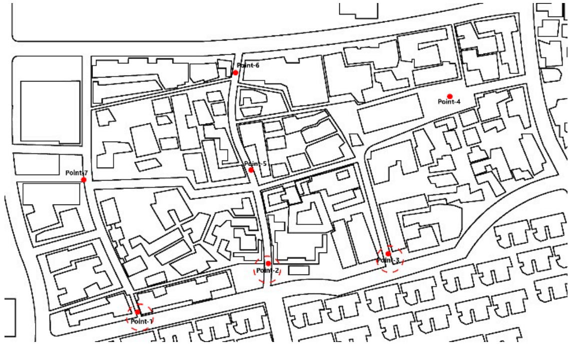
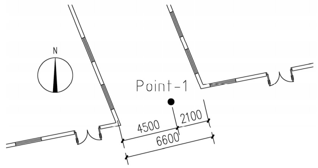
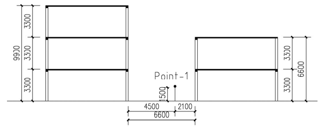
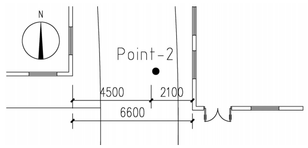
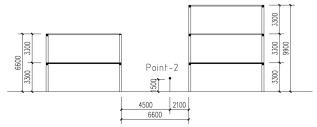
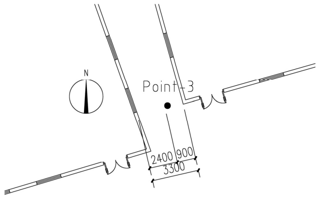
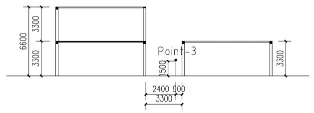
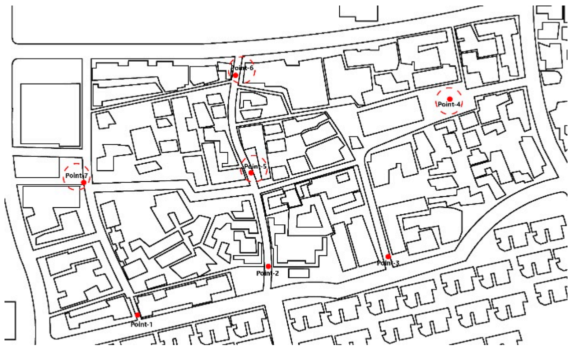
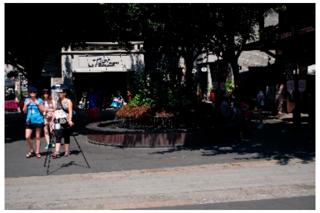
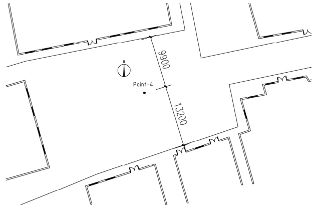
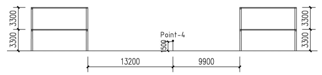
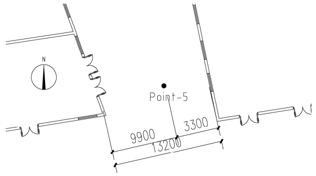
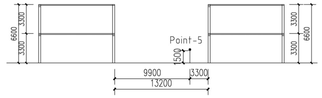
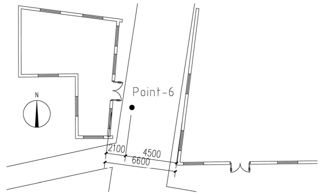
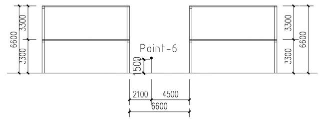
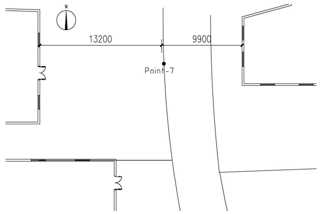
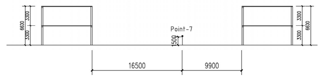
	Point	Photo	Plane	Section
	1			
	2			
	3			

Table 2. *Cont.*

	Point	Photo	Plane	Section
	4			
	5			
	6			
	7			

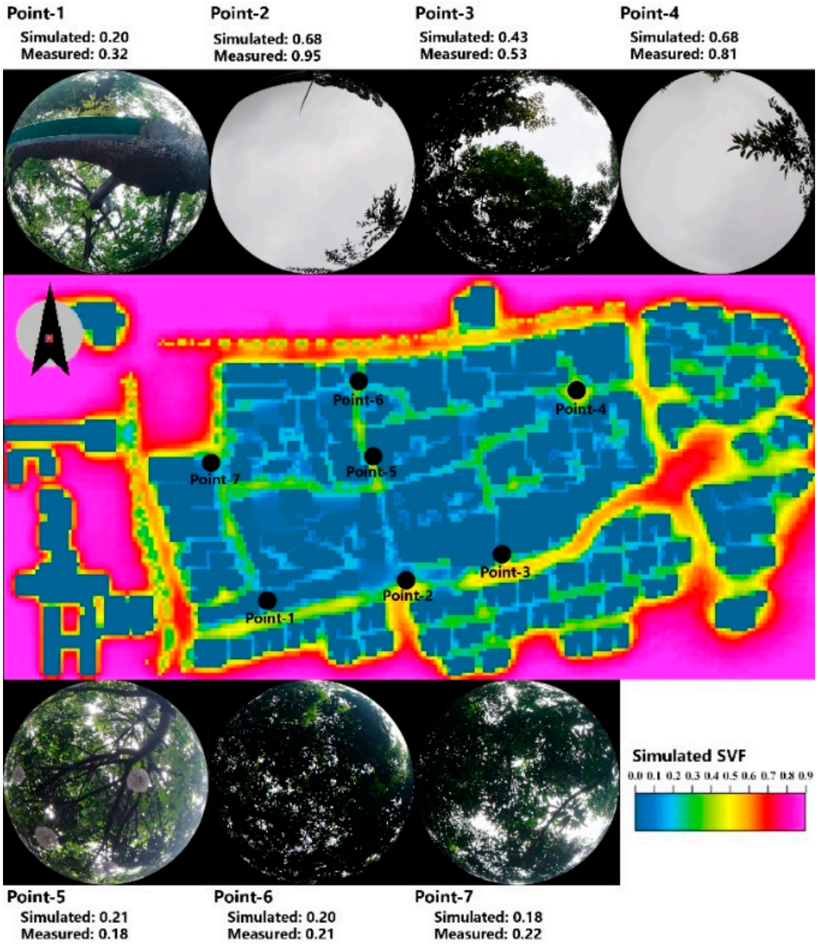


Figure 7. A comparison of simulated and measured sky view factor (SVF).

2.2. Methodology

The methodological framework is shown in Figure 8. The current work consisted of field measurements, a questionnaire survey, and numerical simulation. The simulated result was compared to the measured result by linear analysis to ensure the accuracy of the simulated result.

The data output by the simulated software, including the mean radiant temperature (MRT), wind velocity, air temperature, and relative humidity, were used as initial data to calculate humans' thermal sensation. Moreover, comparing the simulated PET index to the questionnaire survey result allowed us to put forward the tourists' acceptable thermal comfort range and neutral PET during the daytime.

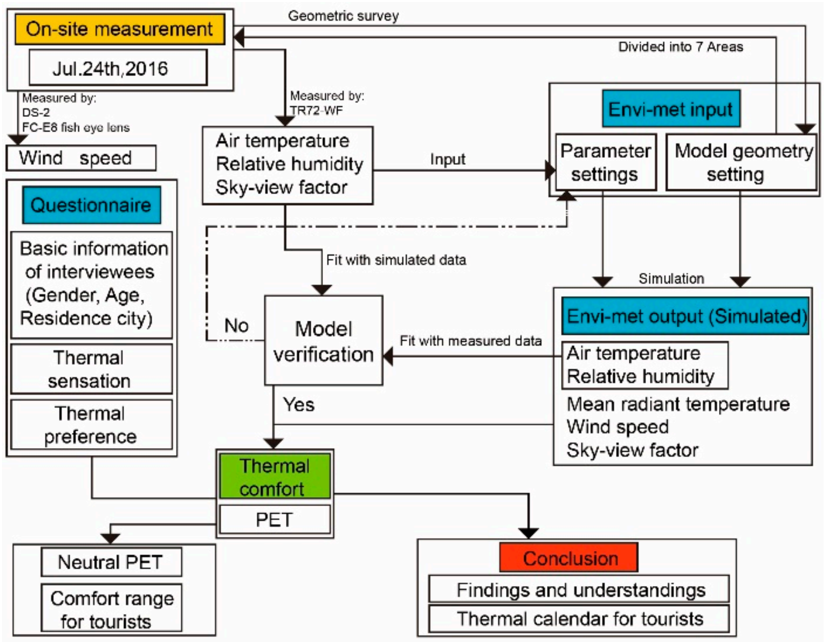


Figure 8. Methodological framework of this study.

2.3. Field Measurements

In order to guarantee the accuracy of the simulated result by ENVI-met and to evaluate humans' thermal comfort, the measurement instruments were fixed 1.5 m above the ground and at least 1.5 m from the wall. In addition, each relative humidity and air temperature recording instrument was covered with a radiation shield to prevent sun radiation from affecting the air temperature during the measurement time. The measured results including wind velocity (m/s), air temperature (°C), and relative humidity (%) were collected each minute. All devices and sensors complied with the standard of ISO7726 [47]. The measurements were conducted on 24 July 2016 and the data were collected from 9:00 a.m. to 5:00 p.m. Table 3 displays the specifications of the measurement instruments.

Table 3. The specifications of the instruments used.

Variable	Sensor	Accuracy	Range	Interval	Mode
Relative humidity	TR-72wf	±5%	10–95%	1 min	Automatic
Air temperature	TR-72wf	±0.5 °C	0–±55 °C	1 min	Automatic
Anemoscope	DS-2	±0.3 m/s	0–70 m/s	1 min	Automatic

2.4. The Questionnaire Survey

As they completed the questionnaires, the climatic instruments were fixed at the distance of one meter from the interviewees. The use of a questionnaire survey can obtain humans' subjective outdoor thermal sensation and comfort sensation. The questionnaire survey was adapted in many past studies and proved to have a high accuracy [48–51].

The whole questionnaire was divided into two parts. The first part was about the subjective sensation of the microclimatic condition at the time of the survey. The second part was about the tourist's personal information including age, gender, and so on. The scale of the questionnaire was in compliance with previous studies [52,53]. The basic question was the assessment of thermal sensation on a nine-point scale (4, very hot; 3, hot; 2, warm; 1, slightly warm; 0, neutral; −1, slightly cool; −2, cool; −3, cold; −4, very cold) called the thermal sensation vote (TSV) [54]. The questionnaire was written in Chinese, and, during the measurement period, the interviews were conducted with randomly selected tourists who were passing by or sitting and chatting around the site; tourists took almost five minutes to finish the questionnaire. The details of the questionnaire are shown in Appendix A.

2.5. Numerical Simulation of this Study

For the three-dimensional microclimate modeling system, the software ENVI-met-4.0(Bochum University, Bochum, Germany) was chosen as the best modeling tool because of the capability in the modeling foundation for computational fluid dynamics (CFD) for setting up plant interactions in an outdoor environment with buildings of different heights and shapes, different paving materials on the ground surface, and vegetation with different configurations [55].

It can also fulfil the requirement of simulation under higher spatial and temporal resolutions, which can provide an accurate model of microclimate parameters. The accuracy of the simulated results was assessed in many previous studies by comparing the simulated result to the measured result [56].

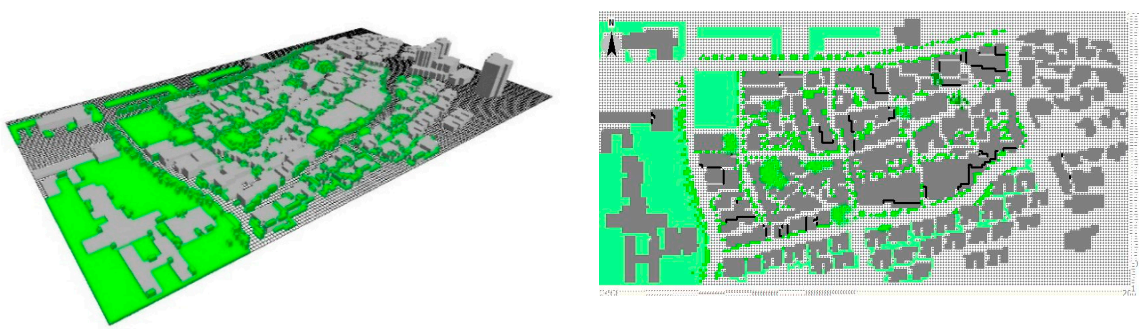
All these studies proved that ENVI-met can simulate an outdoor environment in various climates. In this study, the buildings in this region, including artificial structures and shading devices, were approximated by cubes, and their scales were configured according to the measured survey and Google maps.

The initial data of different meteorological parameters utilized in finishing our work are shown in Table 4.

Table 4. Initial data for simulation.

Input for Simulation	Value
Starting time	12:00 a.m., 24 July 2016
Total simulation time	24 h
Wind speed in 10 m (m/s)	1.8
Wind direction	145
Initial air temperature (°C)	37
Relative humidity (%)	55
Roughness length	0.1
No. of x grids	200
No. of y grids	100
No. of z grids	30
Grid of dx (m)	3
Grid of dy (m)	3
Grid of dz (m)	3
Albedo ground	0.4
Albedo roof	0.2
Albedo wall	0.3

The total simulated time was 24 h, starting from 12:00 a.m. on 24 July 2016 with the simulation assessing each one-minute period. The simulated outcome was output on an hourly basis. The simulated model of this region is shown in Figure 9.



(**a**) (**b**)

Figure 9. The simulated model: (**a**) perspective of the model; (**b**) plan of the model.

2.6. The Index for Assessing Thermal Comfort

There are many indices that evaluate outdoor thermal comfort, such as the predicted mean vote (PMV) [57], standard effective temperature (SET) [58], effective temperature (ET) [59], outdoor standard effective temperature (OUT-SET) [60], universal thermal climate index (UTCI) [61], and physiological equivalent temperature (PET) [62].

PMV is an index based on the basic equation of human thermal balance and the level of the subjective thermal sensation in psychophysiology. It takes into account the comprehensive evaluation index of many related factors of human thermal sensation.

SET is an index which represents the dry-bulb temperature of a hypothetical inner environment at 50% relative humidity for subjects wearing clothing that would be standard for the given activity in a real environment.

ET is the temperature at which motionless saturated air can induce the same sensation of comfort as that induced by the real conditions of air temperature, humidity, and air movement.

OUT-SET is similar to the SET index, but it is widely used in outdoor environments.

UTCI is set as an isothermal air temperature and simulates dynamic physiological results by mixing advanced clothing models with a thermoregulatory model.

PET is an index which is based on the energy balance of the human body and is known to us as the air temperature that makes thermal conditions in an indoor space be in balance with the core and skin temperature in an outdoor environment. This index is defined for a 35-year-old man 75 kg in weight, 1.75 m tall, with clothing insulation of 0.08 m^2K/W, and a metabolic rate of 164.49 W/m^2 in the summer [62]. Moreover, this index was approved as an outdoor thermal comfort index by the VDI standard of Germany.

ENVI-met's Biomet is a reliable tool to calculate human PET during the daytime, which is based on simulated data including air temperature, relative humidity, wind speed, and mean radiant temperature.

3. Results

3.1. Questionnaire Survey about Human Thermal Comfort

The questionnaire was distributed around the selected points to assess thermal comfort. A total of 241 questionnaires were finished in the measured day; because the measurement period occurred in the heat of summer, most of the respondents wore short sleeves and shorts. The number of questionnaires completed at each point is shown in Table 5.

Table 5. The number of valid questionnaires completed at each point.

Point	1	2	3	4	5	6	7
No.	35	36	31	42	35	30	32

In general, the respondents were 53.96% female and 46.34% male, and all the questionnaires were completed by tourists, most of whom came for entertainment and some came for the cuisine in this region; in addition, for half of the interviewees, it was their first time coming to the commercial block.

The classification of thermal sensation in a hot-summer and warm-winter climate region according to previous research is shown in Table 6 [30].

The measurement and the questionnaire were both completed in the hottest month of a year; as time increased in the measurement site, tourists' thermal comfort level decreased with the increased warmth. The interviewees' reported thermal sensation is shown in Figure 10. The final results show the tourists' thermal sensation over the whole measured day. From the result of the questionnaires, about 7.28% of the tourists chose "slightly warm", 41.73% chose "hot", 15.65% chose "warm", and the remaining 33.04% chose "very hot".

Table 6. Thermal sensation in a hot-summer and warm-winter climate zone [30].

Sensation	PET (°C)
Very cold	<13
Cold	13–17
Cool	17–21
Slightly cool	21–25
Neutral	25–29
Slightly warm	29–33
Warm	33–37
Hot	37–41
Very hot	>41

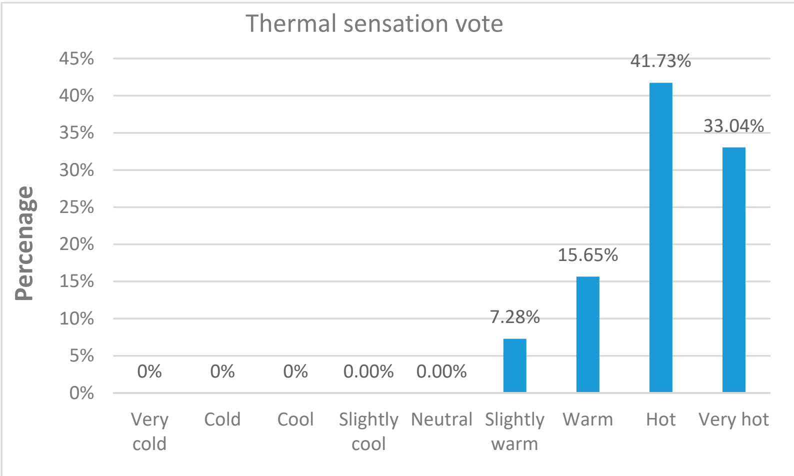
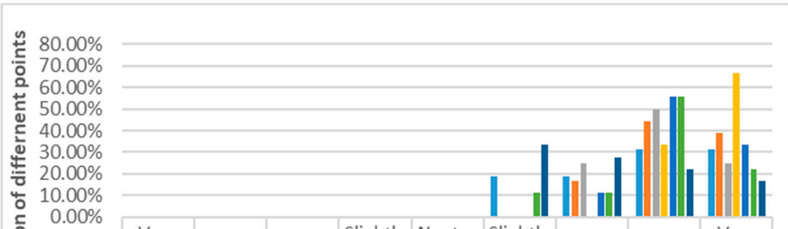


Figure 10. Percentages of thermal sensation votes (TSVs) for this zone.

The percentage distributions of the thermal sensation votes at each selected point are shown in Figure 11.



	Very cold	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Very hot
point-1	0.00%	0.00%	0.00%	0.00%	0.00%	18.75%	18.75%	31%	31.25%
point-2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	16.66%	44.44%	38.90%
point-3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	25.00%	50.00%	25.00%
point-4	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	33.33%	66.67%
point-5	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	11.11%	55.55%	33.34%
point-6	0.00%	0.00%	0.00%	0.00%	0.00%	11.11%	11.11%	55.55%	22.23%
Point-7	0.00%	0.00%	0.00%	0.00%	0.00%	33.33%	27.77%	22.22%	16.68%

Figure 11. Percentages of thermal sensation votes (TSVs) at each point.

It shows that point 4 is the hottest area of this commercial region, while point 7 has the best outdoor environment. Even though both point 4 and point 7 are open space, because the coverage ratio of trees of the former is less than that of the latter, point 7 has better outdoor surroundings. In canyon space, point 1 has the highest appraisal due to its higher aspect ratio (H/W) and sufficient coverage of trees. In addition, point 2 is the worst site, because of the lack of vegetation.

Human thermal sensation is usually determined by finding the correlation between the index PET and thermal sensation vote (TSV). A simple linear regression can be performed between the PET and the thermal sensation vote (TSV) [54]. Figure 12 and Equation (1) show the relationship between the two factors.

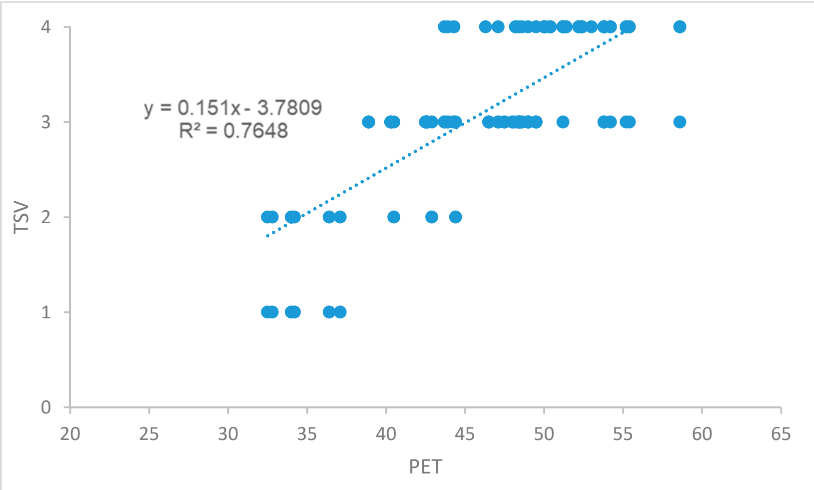


Figure 12. Correlation between TSV and physiological equivalent temperature (PET).

The thermal comfort range is based on the nine-point thermal sensation scale, ranging from −4 to +4 with an acceptable comfort range from −0.5 to +0.5 found in a previous study [63]. Therefore, the thermal comfort sensation of the tourists in this zone ranges from 22 °C to 28 °C

$$TSV = 0.151PET - 3.7809\left(R^2 = 0.7648\right). \quad (1)$$

PET and the neutral PET is 25 °C (MTSV = 0), similar to a previous study in Hong Kong [22,23]. As we all know, different climate regions have different climates; in addition, different seasons have various thermal comfort ranges because of various weather conditions. So far, previous studies showed that the cold season will have a lower comfort range than the warm season [63,64], and researchers approximated the comfort ranges of subtropical, hot, arid, and tropical climates. In this study, the interviewees were all tourists and did not include native persons who are more tolerant to heat stress in the outdoor environment; considering the influence of native persons may lead to an extension of the comfort range.

3.2. The Results of Measurement and Simulation

3.2.1. The Measured Data

The collected wind velocity is displayed in Table 7, which shows the average data from the seven sites.

Table 7. The collected wind velocity data from the seven points (m/s).

Point	1	2	3	4	5	6	7
24 July	0.43	0.54	0.35	0.32	0.27	0.32	0.35

All the data show that the commercial zone stays in a calm wind area, which explains why the tourists' thermal sensation in this zone will not be obviously influenced by the wind velocity.

3.2.2. The Correlation between Measured and Simulated Data

The regression analysis of relative humidity and air temperature between the measured and simulated data is shown in Figure 12. The values of R^2 of the two factors varied from 0.7544 to 0.9847; according to previous studies [24–29], the final result of this study shows that the software can be a reliable tool for simulating human thermal sensation. However, as shown in Figure 13, point 4 has the highest error, where the deviation of air temperature can reach 6 °C. Such a high magnitude of deviation can be attributed to the position of the point. Due to consideration of the tourists' safety, the loggers could not be fixed in the center of this space; instead, we installed them next to the sidewalk.

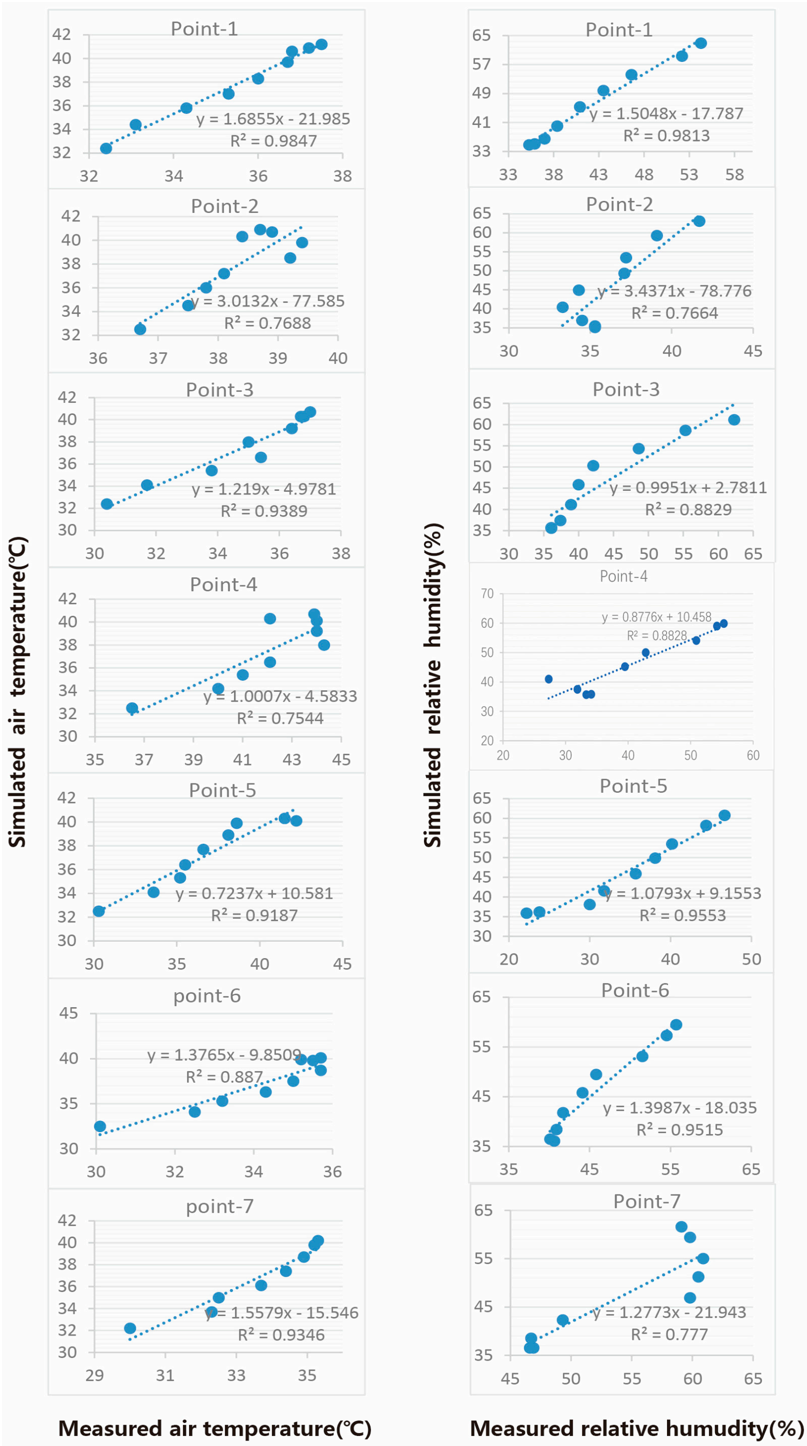


Figure 13. The regression analysis between the measured and simulated data for 24 July.

3.2.3. Tourists' Thermal Comfort at the Hottest Time of Day

As mentioned above, the PET index is a significant factor in determining human thermal sensation in a hot summer. A previous study showed that the worst thermal comfort conditions always occur from 2:00 p.m. to 4:00 p.m. in both the actual measurement and the simulation result. In this study, the final simulated images in Figure 14 show the distribution of PET across the commercial zone for the 24 July scenario at 2:00 p.m. According to the diagram, the PET values show that, on the measured day, deeper canyons have a better range of PET values than the shallower canyons; this is similar to the findings of this study that concluded that shading can reduce the discomfort area in cities and also recommends increased shading and aspect ratio (H/W) to reduce the PET [26]. The PET values of the vegetation-covered areas in the diagram are obviously lower than those of the surrounding region. This modification can be attributed to the different effect of different parameters such as grass, trees, and water bodies. Grass can modify outdoor thermal stress by transpiration. Trees also provide this function through transpiration and supplying shading to impede radiation during the daytime. According to the thermal sensation in the hot-summer and warm-winter climate area, all the measured points covered by the different levels range absolutely within "very hot".

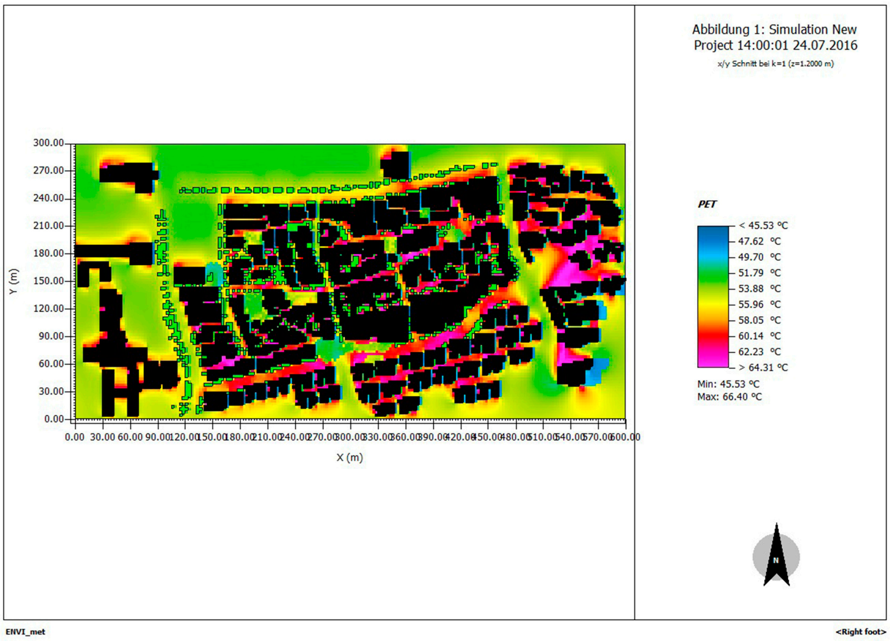


Figure 14. Distribution of PET (2:00 p.m.) at Z = 1.5 m of the base case.

3.3. The Thermal Calendar for Tourists in Extreme Summer

In order to compare the thermal conditions in this whole region, the PET during the daytime (for the measured day) is shown in Figure 15.

According to the final results of thermal sensation during daytime, the minor gap in thermal conditions at each of the different points occurred at 1:00 p.m. (4.6 °C PET) and the major one was at 8:00 a.m. (13.1 °C PET).

The thermal calendars can help tourists to select a comfortable time to visit this commercial pedestrianized zone during the hot summer. The outdoor thermal sensation of this zone is defined at each one-hour interval from 8:00 a.m. to 12:00 p.m., and each color in this thermal calendar represents a nearly 2 °C interval of the PET. It is necessary to provide a most suitable period for tourists, and it is easy for us to define "very hot" and "hot" as "unsuitable", "warm" as "fairly suitable", and "slightly warm" as "suitable".

Figure 16 shows the thermal comfort calendar of the base case. At 8:00 a.m. and 9:00 a.m., except for point 4 being "unsuitable", all other points are "suitable" or "fairly suitable"; point 3 and point 6 are "suitable", and points 1, 2, 5, and 7 are all "fairly suitable". From 10:00 a.m. to 7:00 p.m., all the sites are not comfortable for visiting, and point 4 has the worst thermal comfort. After 7:00 p.m., all the points can be visited comfortably.

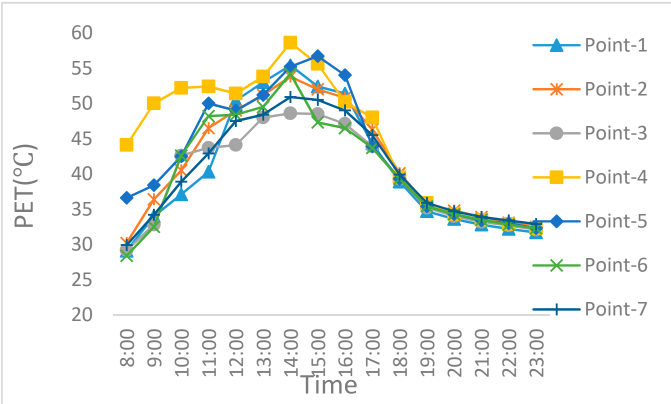


Figure 15. Comparison of thermal comfort of this whole region during daytime.

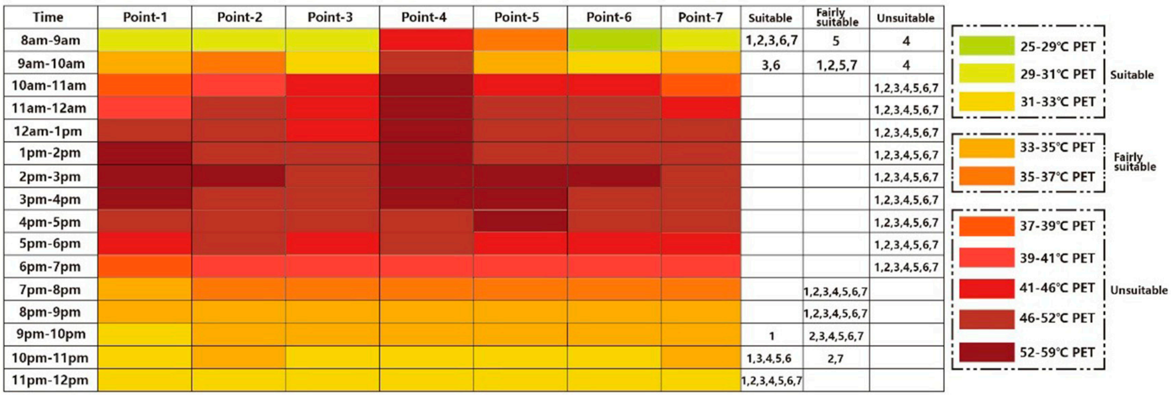


Figure 16. Thermal comfort calendar for visiting tourists under the existing scenario.

4. Conclusions and Outlook

Due to its economic value, urban tourism became a significant factor increasing the financial income of a city. Most previous studies on tourism assessed data collected through different meteorological stations [3,4] and put forward thermal comfort conditions regardless of the importance of the numerical simulation and questionnaire survey.

The present study intended to evaluate tourists' thermal sensation in the microclimate of the commercially valuable pedestrianized zone of Fo Shan city on the hottest day of the year, as this zone attracts many tourists every year. The acceptable thermal sensation for tourists in this zone ranges from 22 to 28 °C PET, and the NPET (outdoor neutral PET) is 25 °C. Because of the high heat stress, 41.73% of the tourists chose "hot" and 33.04% chose "very hot" to describe their thermal sensation. Even though the tourists were from different places, their thermal sensation was close to the climate classification in the hot-summer and warm-winter region. According to the final simulated results, almost none of the selected areas are within the comfort zone during the daytime from 10:00 a.m. to 7:00 p.m. In addition, in the early morning (8:00 a.m. to 10:00 a.m.), except for open space (point 4), all points are in the comfortable zone. From 7:00 p.m. to 12:00 p.m., the whole zone has a comfortable temperature. The comparison of the thermal conditions of different sites is the significant factor regarding selecting the suitable visiting time range. It is concluded that the site with higher heat stress in the simulated process will have worse thermal conditions. In order to increase local tourism income, improving tourists' thermal sensation is necessary.

According to the final results and previous studies [23–32], we developed the following suggestions for designers and local managers: (1) increasing average building height can provide shading area and impede solar radiation for tourists, thus improving outdoor thermal sensation; (2) because of the cooling effect of vegetation, increasing its coverage ratio including tree and grass can ameliorate heat stress directly; in addition, it can also improve the subjective sensation of humans by supplying attractive scenery; (3) reducing the coverage ratio of hardened ground is another important way to reduce heat stress.

Also, we need to solve more problems in our future studies. Firstly, under the result of this study, we will continue finding the most effective method in improving thermal sensation and putting forward new thermal calendars for tourists. Secondly, in this study, we only consider a single tree species. It is very important to consider more species in future work. Thirdly, it is important to mention that the building façade material in ENVI-met software is assumed to be the same material, but this may not be the case in the real world.

Author Contributions: Conceptualization, X.M.; methodology, X.M.; software, X.M.; validation, X.M., H.F. and D.Z.; formal analysis, H.F.; investigation, H.F. and D.Z.; resources, D.Z.; data curation, D.Z.; writing—original draft preparation, X.M.; writing—review and editing, M.W.; visualization, H.F. and D.Z.; supervision, H.F. and D.Z.; project administration, D.Z.; funding acquisition, D.Z.

Funding: This research was funded by the Natural Science Foundation of China, under the project No. 2013FY112500.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Outdoor Thermal Comfort Questionnaire
Note: This questionnaire is entirely voluntary.

1. How do you feel at this moment? (Please mark the option below)
   −4 Too Cold −3 Cold −2 Cool −1 Slightly cool 0 Neutral 1 Slightly warm
   2 Warm 3 Hot 4 Too hot
2. How would you describe your comfort level at this moment?
   Comfortable Slightly uncomfortable Uncomfortable
   Too uncomfortable Much too uncomfortable
3. Which of the following best describes how you feel at this moment?
   Too cool Slightly cool Cool Neutral Slightly warm Warm
4. How do you feel about the environment?
   Completely tolerable Slightly intolerable Too intolerable Much too intolerable Intolerable
5. According to your personal experience, do you prefer this environment?
   Yes No
6. How old are you?
   Less than 20 20–30 30–40 40–50 50–60 60–70 More than 70
7. An introduction about the interviewee (gender, city of residence, and so on)
8. The climate conditions of the measurement site
9. The time of the survey
10. Something else

References

1. Matzarakis, A. Weather-and climate-related information for tourism. *Tour. Hosp. Plan.* **2006**, *3*, 99–115. [CrossRef]
2. de Freitas, C.R.; Scott, D.; McBoyle, G. A second generation climate index for tourism (CIT): Specification and verification. *Int. J. Biometeorol.* **2008**, *52*, 399–407. [CrossRef] [PubMed]
3. Bigano, A.; Hamilton, J.M.; Tol, R.S. The impact of climate on holiday destination choice. *Clim. Chang.* **2006**, *76*, 389–406. [CrossRef]

4. Eugenio-Martin, J.L.; Campos-Soria, J.A. Climate in the region of origin and destination choice in outbound tourism demand. *Tour. Manag.* **2010**, *31*, 744–753. [CrossRef]
5. Ridderstaat, J.; Oduber, M.; Croes, R.; Nijkamp, P.; Martens, P. Impacts of seasonal patterns of climate on recurrent fluctuations in tourism demand: Evidence from Aruba. *Tour. Manag.* **2014**, *41*, 245–256. [CrossRef]
6. Lu, S.; Xia, H.; Wei, S.; Fang, K.; Qi, Y. Analysis of the differences in thermal comfort between locals and tourists and genders in semi-open spaces under natural ventilation on a tropical island. *Energy Build.* **2016**, *129*, 264–273. [CrossRef]
7. Matzarakis, A.; Mayer, H. Heat stress in Greece. *Int. J. Biometeorol.* **1997**, *41*, 34–39. [CrossRef] [PubMed]
8. Lecha, L.; Shackleford, P. Climate services for tourism and recreation. *Bull. World Meteorol. Organ.* **1997**, *46*, 46.
9. Mieczkowski, Z. The tourism climatic index: A method of evaluating world climates for tourism. *Can. Geogr. Goeogr. Can.* **1985**, *29*, 220–233. [CrossRef]
10. Shiue, I.; Matzarakis, A. Estimation of the tourism climate in the Hunter Region, Australia, in the early twenty-first century. *Int. J. Biometeorol.* **2011**, *55*, 565–574. [CrossRef] [PubMed]
11. de Freitas, C.R. Tourism climatology: Evaluating environmental information for decision making and business planning in the recreation and tourism sector. *Int. J. Biometeorol.* **2003**, *48*, 45–54. [CrossRef] [PubMed]
12. Yan, Y.Y. Human thermal climates in China. *Phys. Geogr.* **2005**, *26*, 163–176. [CrossRef]
13. Lin, T.P.; Matzarakis, A. Tourism climate and thermal comfort in Sun MoonLake, Taiwan. *Int. J. Biometeorol.* **2008**, *52*, 281–290. [CrossRef] [PubMed]
14. Farajzadeh, H.; Matzarakis, A. Evaluation of thermal comfort conditions in Ourmieh Lake, Iran. *Theor. Appl. Climatol.* **2012**, *107*, 451–459. [CrossRef]
15. Matzarakis, A.; Rammelberg, J.; Junk, J. Assessment of thermal bioclimate and tourism climate potential for central Europedthe example of Luxembourg. *Theor. Appl. Climatol.* **2013**, *114*, 193–202. [CrossRef]
16. Oke, T.R. Street design and urban canopy layer climate. *Energy Build.* **1988**, *11*, 103–113. [CrossRef]
17. Liu, W.; Zhang, Y.; Deng, Q. The effects of urban microclimate on outdoor thermal sensation and neutral temperature in hot-summer and cold-winter climate. *Energy Build.* **2016**, *128*, 190–197. [CrossRef]
18. Chen, H.; Ooka, R.; Harayama, K.; Kato, S.; Li, X. Study on outdoor thermal environment of apartment block in Shenzhen, China with coupled simulation of convection, radiation and conduction. *Energy Build.* **2004**, *36*, 1247–1258. [CrossRef]
19. Zacharias, J.; Stathopoulos, T.; Wu, H. Microclimate and downtown open space activity. *Environ. Behav.* **2001**, *33*, 296–315. [CrossRef]
20. Nastos, P.T.; Matzarakis, A. The effect of air temperature and human thermal indices on mortality in Athens, Greece. *Theor. Appl. Climatol.* **2012**, *108*, 591–599. [CrossRef]
21. Strømann-Andersen, J.; Sattrup, P.A. The urban canyon and building energy use: Urban density versus daylight and passive solar gains. *Energy Build.* **2011**, *43*, 2011–2020. [CrossRef]
22. Taleb, H.; Taleb, D. Enhancing the thermal comfort on urban level in a desert area: Case study of Dubai, United Arab Emirates. *Urban For. Urban Green.* **2014**, *13*, 253–260. [CrossRef]
23. Fröhlich, D.; Matzarakis, A. Modeling of changes in thermal bioclimate: Examples based on urban spaces in Freiburg, Germany. *Appl Clim.* **2013**, *111*, 547–558. [CrossRef]
24. Mochida, A.; Tabata, Y.; Iwata, T.; Yoshino, H. Examining tree canopy models for CFD prediction of wind environment at pedestrian level. *J. Wind Eng. Ind. Aerodyn.* **2008**, *96*, 1667–1677. [CrossRef]
25. Jamei, E.; Rajagopalan, P.; Seyedmahmoudian, M.; Jamei, Y. Review on the impact of urban geometry and pedestrian level greening on outdoor thermal comfort. *Renew. Sustain. Energy Rev.* **2016**, *54*, 1002–1017. [CrossRef]
26. Krüger, E.; Pearlmutter, D.; Rasia, F. Evaluating the impact of canyon geometry and orientation on cooling loads in a high-mass building in a hot dry environment. *Appl. Energy* **2010**, *87*, 2068–2078. [CrossRef]
27. Cao, A.; Li, Q.; Meng, Q. Effects of orientation of urban roads on the local thermal environment in guang zhou city. *Procedia Eng.* **2015**, *121*, 2075–2082. [CrossRef]
28. Zhang, Y.; Du, X.; Shi, Y. Effects of street canyon design on pedestrian thermal comfort in the hot-humid area of China. *Int. J. Biometeorol.* **2017**, *61*, 1421–1432. [CrossRef]
29. Pearlmutter, D.; Berliner, P.; Shaviv, E. Integrated modeling of pedestrian energy exchange and thermal comfort in urban street canyons. *Build. Environ.* **2007**, *42*, 2396–2409. [CrossRef]

30. Morakinyo, T.E.; Lam, Y.F. Simulation study on the impact on tree-configuration, planting pattern and wind condition on street-canyon's micro-climate and thermal comfort. *Build. Environ.* **2016**, *103*, 262–275. [CrossRef]
31. Morakinyo, T.E.; Kong, L.; Lau, K.K.-L.; Yuan, C.; Ng, E. A study on the impact of shadow-cast and tree species on in-canyon and neighborhood's thermal comfort. *Build. Environ.* **2017**, *115*, 1–17. [CrossRef]
32. Erell, E.; Pearlmutter, D.; Boneh, D.; Kutiel, P.B. Effect of high-albedo materials on pedestrian heat stress in urban street canyons. *Urban Clim.* **2014**, *10*, 367–386. [CrossRef]
33. Shashua-Bar, L.; Tsiros, I.X.; Hoffman, M.E. A modeling study for evaluating passive cooling scenarios in urban streets with trees. Case study: Athens, Greece. *Build. Environ.* **2010**, *45*, 2798–2807. [CrossRef]
34. Oliveira, S.; Andrade, H.; Vaz, T. The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon. *Build. Environ.* **2011**, *46*, 2186–2194. [CrossRef]
35. Thimonier, A.; Sedivy, I.; Schleppi, P. Estimating leaf area index in different types of mature forest stands in Switzerland: A comparison of methods. *Eur. J. For. Res.* **2010**, *129*, 543–562. [CrossRef]
36. Miller, J.B. A formula for average foliage density. *Aust. J. Bot.* **1967**, *15*, 141–144. [CrossRef]
37. Zhao, L.; Zhou, X.; Li, L.; He, S.; Chen, R. Study on outdoor thermal comfort on a campus in a subtropical urban area in summer. *Sustain. Cities Soc.* **2016**, *22*, 164–170. [CrossRef]
38. Yang, A.; Juan, Y.; Wen, C.; Chang, C. Numerical simulation of cooling effect of vegetation enhancement in a subtropical urban park. *Appl. Energy* **2017**, *192*, 178–200. [CrossRef]
39. Huang, K.; Li, Y. Impact of street canyon typology on building's peak cooling energy demand: A parametric analysis using orthogonal experiment. *Energy Build.* **2017**, *154*, 448–464. [CrossRef]
40. Hamada, S.; Ohta, T. Seasonal variations in the cooling effect of urban green areas on surrounding urban areas. *Urban For. Urban Green.* **2010**, *9*, 15–24. [CrossRef]
41. Saito, I.; Ishihara, O.; Katayama, T. Study of the effect of green areas on the thermal environment in an urban area. *Energy Build* **1990**, *15*, 493–498. [CrossRef]
42. Katayama, T.; Ishii, A.; Hayashi, T.; Tsutsumi, J. Field surveys on cooling effects of vegetation in an urban area. *J. Therm. Biol.* **1993**, *18*, 571–576. [CrossRef]
43. Cultural Heritage and Tourism Organization of Fo Shan. Available online: http://www.foshan.gov.cn/gzjg/fswenhua/lydt/ (accessed on 1 April 2019).
44. TDCFCB. Thermal Design Code for Civil Buildings, GB 50176–51993. Available online: https://zhidao.baidu.com/question/492628757.html (accessed on 1 April 2019).
45. Kottek, M.; Grieser, J.; Beck, C.; Rudolf, B.; Rubel, F. World map of the Köppen-Geiger climate classification updated. *Meteorol. Z.* **2006**, *15*, 259–263. [CrossRef]
46. Meteorological Organization Country. Available online: http://www.irimo.ir (accessed on 1 January 2019).
47. ISO. *International Standard 7726, Thermal Environment-Instruments and Method for Measuring Physical Quantities*; International Standard Organization: Geneva, Switzerland, 1998.
48. Sharmin, T.; Steemers, K.; Matzarakis, A. Analysis of microclimatic diversity and outdoor thermal comfort perceptions in the tropical megacity Dhaka, Bangladesh. *Build. Environ.* **2015**, *94*, 734–750. [CrossRef]
49. Lai, D.; Guo, D.; Hou, Y.; Lin, C.; Chen, Q. Studies of outdoor thermal comfort in northern China. *Build. Environ.* **2014**, *77*, 110–118. [CrossRef]
50. Lin, T. Thermal perception, adaptation and attendance in a public square in hot and humid regions. *Build. Environ.* **2009**, *44*, 2017–2026. [CrossRef]
51. Yang, B.; Olofsson, T.; Nair, G.; Kabanshi, A. Outdoor thermal comfort under subarctic climate of north Sweden—A pilot study in Umeå. *Sustain. Cities Soc.* **2017**, *28*, 387–397. [CrossRef]
52. Standard 55. *Thermal Environment Conditions for Human Occupancy*; Amer Society of Heating: Atlanta, GA, USA, 2013.
53. Villadiego, K.; Velay-Dabat, M.A. Outdoor thermal comfort in a hot and humid climate of Colombia: A field study in Barranquilla. *Build. Environ.* **2014**, *75*, 142–152. [CrossRef]
54. De Dear, R.J.; Brager, G.S. Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55. *Energy Build.* **2002**, *34*, 549–561. [CrossRef]
55. Bruse, M. ENVI-met, 2014, 4. Available online: http://www.ENVI-met.info (accessed on 1 January 2019).
56. Middel, A.; Häb, K.; Brazel, A.J.; Martin, C.A.; Guhathakurta, S. Impact of urban form and design on mid-afternoon microclimate in Phoenix Local Climate Zones. *Landsc. Urban Plan.* **2014**, *122*, 16–28. [CrossRef]
57. Fanger, P.O. *Thermal Comfort*; McGraw Hill: New York, NY, USA, 1972.

58. Gagge, A.P.; Fobelets, A.P.; Berglund, L.G. A standard predictive index of human respond to the thermal environment. *Ashare Trans.* **1986**, *92*, 709–731.
59. De Dear, R.; Pickup, J. An outdoor thermal environment index (OUT_SET*)-applications. In *Biometeorology and Urban Climatology at the Turn of the Millenium, Proceedings of the ICB-ICUC'99 Conference, Sydney, Australia, 8–12 November 1999*; de Dear, R.J., Kalma, J.D., Oke, T.R., Auliciems, A., Eds.; WCASP-50, WMO/TD No. 1026; World Meteorological Organization: Geneva, Switzerland, 2000.
60. Spagnolo, J.; de Dear, R.J. A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia. *Build. Environ.* **2003**, *38*, 721–738. [CrossRef]
61. Mahmoud, A.H.A. Analysis of the microclimatic and human comfort conditions in an urban park in hot and arid regions. *Build. Environ.* **2011**, *46*, 2641–2656. [CrossRef]
62. Höppe, P. The physiological equivalent temperature—A universal index for the bio-meteorological assessment of the thermal environment. *Int. J. Biometeorol.* **1999**, *43*, 71.
63. Xu, C.; Li, S.; Zhang, X.; Shao, S. Thermal comfort and thermal adaptive behaviours in traditional dwellings: A case study in Nanjing, China. *Build. Environ.* **2018**, *142*, 153–170. [CrossRef]
64. Nikolopoulou, M.; Baker, N.; Steemers, K. Thermal comfort in outdoor urban spaces: Understanding the human parameter. *Sol. Energy* **2001**, *70*, 227–235. [CrossRef]